BBC

FINDING THE FIRST BLACK HOLE COLLISIONS

How gravitational wave astronomy is coming of age

#196 SEPTEMBER 2021

Sky at Night

THE UK'S BEST SELLING ASTRONOMY MAGAZINE

DARK SKIES ON YOUR DOORSTEP

Top sights for long nights this autumn and winter

THE TELESCOPES THAT CHANGED ASTRONOMY

Discover the instruments that have revolutionised the way we see the Universe

METROPOLIS ON THE MOON

Observe the 'streets' of Gruithuisen's lunar city

CAREERS ABOVE THE CLOUDS

A students' guide to getting ahead in the thriving space sector

A PLANETARY PUZZLE

Solving the mysteries of Solar System formation

INCONSTANT LIGHT

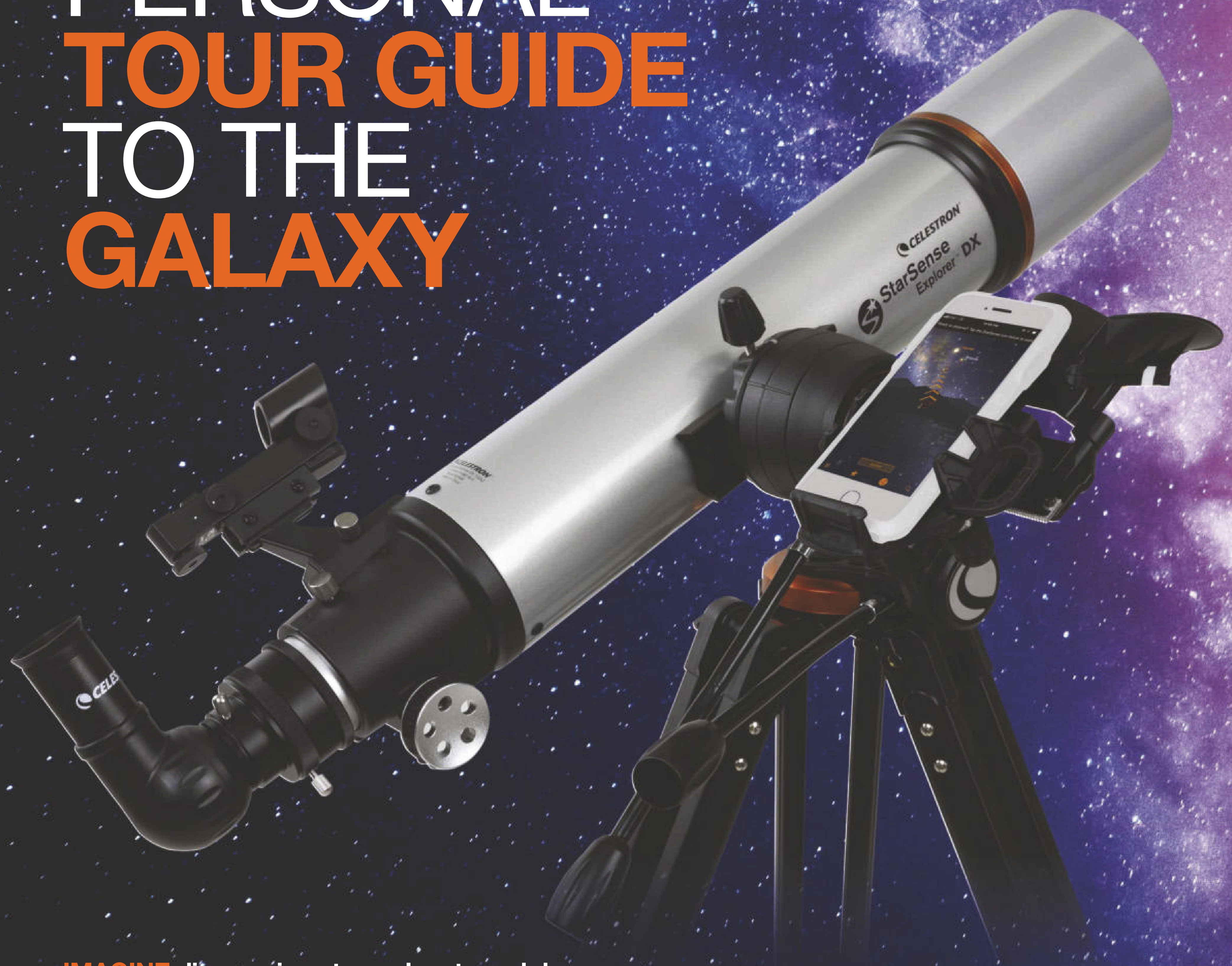
The best variable stars to track in late summer

EYEPIECE NOT INCLUDED

On test: the telescope you don't need to look through

CELESTRON

YOUR PERSONAL **TOUR GUIDE** TO THE **GALAXY**



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Welcome

Celebrating the telescopes that have changed astronomy

When Galileo recorded his magnified observations of the Moon and the planets with a modified new Dutch invention, the telescope, he could hardly have foreseen the revolution in understanding he had set in motion. Today, a little over 400 years since the Galilean moons were first observed, the telescope has enabled us to see beyond the visible spectrum and back to the primordial cosmos. Turn to **page 26** to read Ezzy Pearson's celebration of the instruments that have perhaps done most to widen the boundaries of our understanding.

It's worth training your own telescope on the skies this month as the nights start to lengthen. On **page 32**, Scott Levine looks at the dark-sky season to preview the treats that lie in store for binocular and naked-eye stargazers, as well as observers at the eyepiece.

With the advent of gravitational wave astronomy, telescopes can now observe outside the electromagnetic spectrum to break new ground. On **page 62**, Govert Schilling looks at plans for the latest instrument to observe minute changes in gravity, the Einstein Telescope, and how it will revolutionise our view of high-energy events across the Universe.

The Einstein Telescope is just one example of many in a thriving space sector pushing ahead with new opportunities. If you're considering a job or qualification in space science, tech or engineering, this issue Hayley Smith of the National Space Academy looks at some of the routes to take to set up a career in this area, and the part that GCSEs, A-Levels and undergraduate studies play. Turn to **page 36** for more, and for Tim Peake's tips on getting ahead.

Enjoy the issue!

Chris Bramley, Editor

PS Our next issue goes on sale on Friday 17 October.

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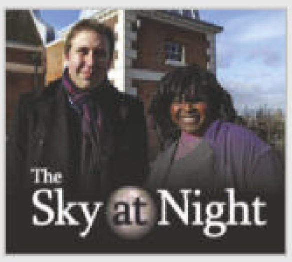
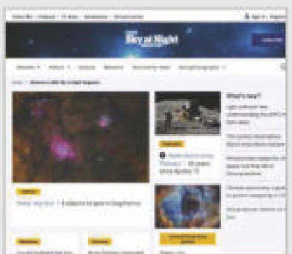
Sky at Night – lots of ways to enjoy the night sky...



Television
Find out what *The Sky at Night* team have been exploring in recent and past episodes on page 16



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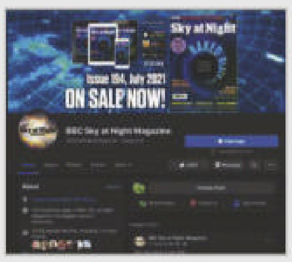

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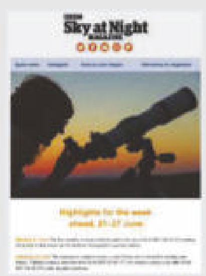

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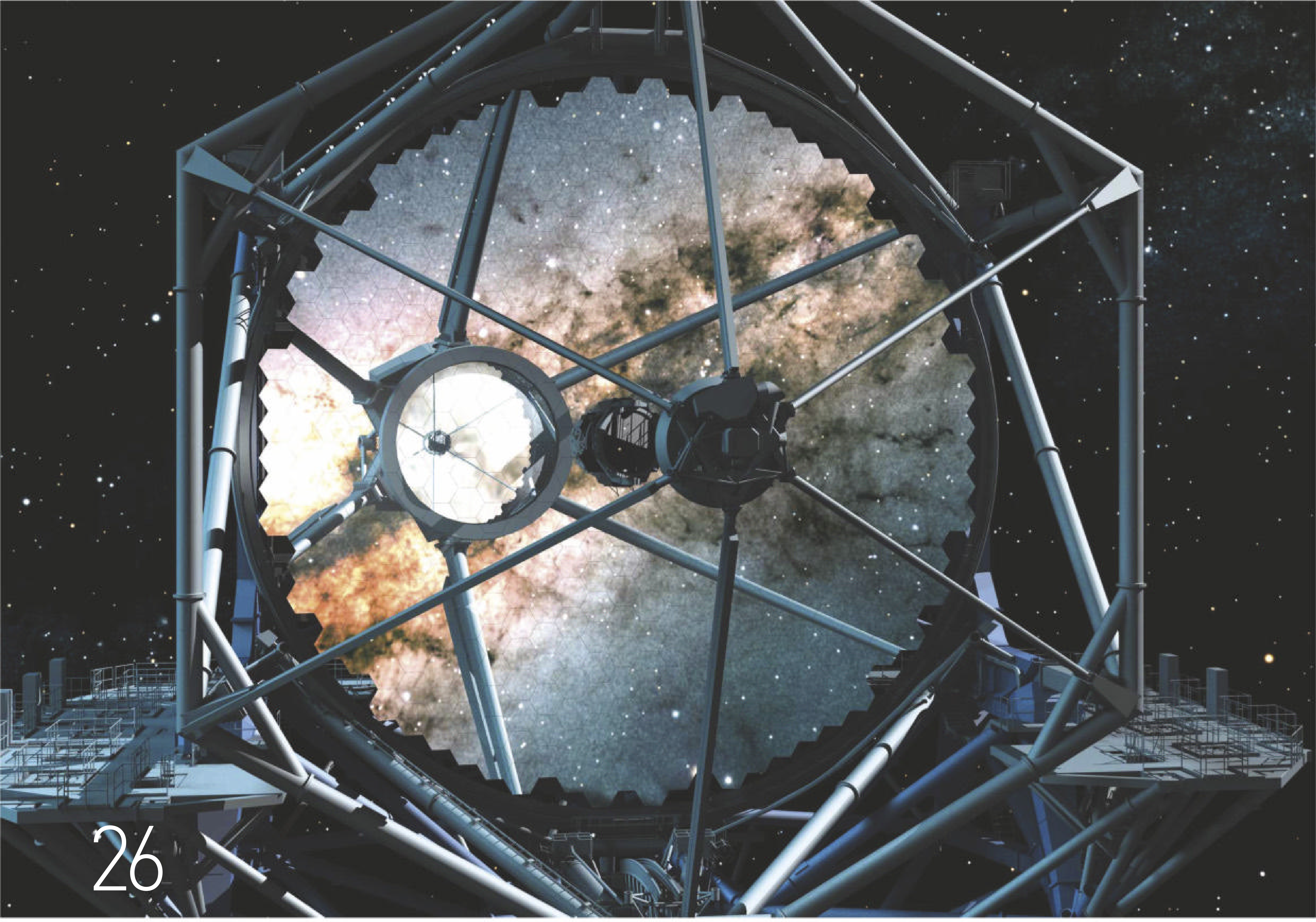

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Ⓒ = on the cover

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The Sky Guide

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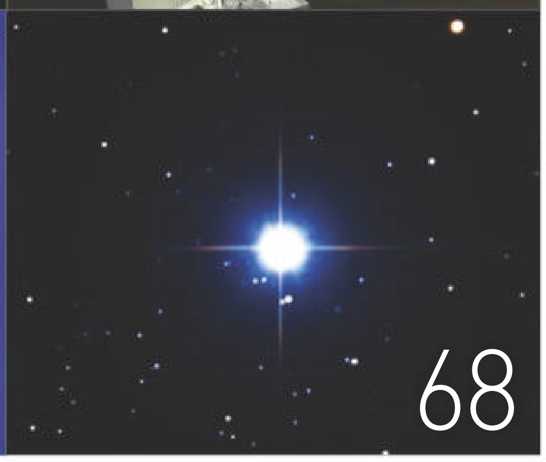
New to astronomy?

To get started, check out our guides and glossary at
www.skyatnightmagazine.com/astronomy-for-beginners



This month's contributors

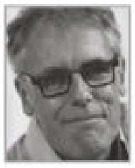
Mary McIntyre

Outreach astronomer

"This model was great fun to build. I have never seen our nearest stellar neighbours presented in this way before and I love the final result." **Mary builds a 3D model of our Sun and its closest stellar neighbours,** **page 74**

Govert Schilling

Astronomy journalist



"I love the Einstein Telescope, as there's a chance that this gravitational wave observatory will be built in my home country: the Netherlands!" **Govert reports on how astronomers will monitor black hole collisions,** **page 62**

Hayley Smith

Space educator

"Ground-breaking scientific discoveries, upcoming Moon and Mars missions... Space is an exciting industry to be part of." **Hayley advises prospective GCSE and A-Level students aiming for the stars,** **page 36**

Extra content ONLINE

Visit **www.skyatnightmagazine.com/bonus-content/582H4HJ/** to access this month's selection of exclusive Bonus Content

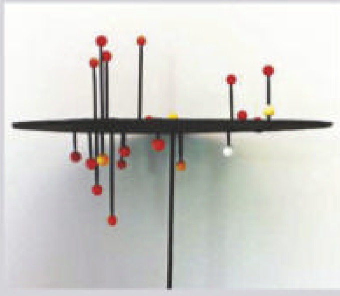
SEPTEMBER HIGHLIGHTS

The world's largest radio telescope

Astrophysicist Carole Mundell on how the Square Kilometre Array will reveal the secrets of the cosmos

Watch *The Sky at Night: ET and the BBC*

Maggie and Chris look back at how the BBC has reported on the search for extraterrestrial life over the past few decades.



Make a model of our celestial neighbours

Download our cosmic distance calculator to help with this month's stellar DIY Astronomy project (see page 74).

The Virtual Planetarium

Pete Lawrence and Paul Abel guide us through the best sights to see in the night sky this month.

CONCERTO DEBUT

A new tool begins scanning for signals from the early Universe, when the first generation of stars were born

APEX/VISTA, 6 JULY 2021

Looking more like a hawk bearing down on its prey than its usual close resemblance to a feline foot, this is the Cat's Paw Nebula as imaged for the first time by CONCERTO.

CONCERTO, which stands for CarbON CII line in post-rEionisation and ReionisaTiOn epoch (we'll just stick with the acronym), is the brand new instrument on board the European Southern Observatory's 12-metre diameter APEX (Atacama Pathfinder Experiment) telescope.

Bringing both imaging and spectroscopy to the table, it has begun scanning the sky at frequencies between infrared and radio waves in search of the radiation emitted by ionised carbon atoms – signatures from the earliest days of the cosmos.

The signal from the reionisation period – 600 million to 1.2 billion years after the Big Bang – is so minute that it calls for a new observing technique, called intensity mapping. This measures the signals from the masses of unresolved sources in order to evaluate their cumulative emission at a given age of the Universe.

The pink and white tones from CONCERTO's data are combined here with near-infrared data from ESO's VISTA telescope.

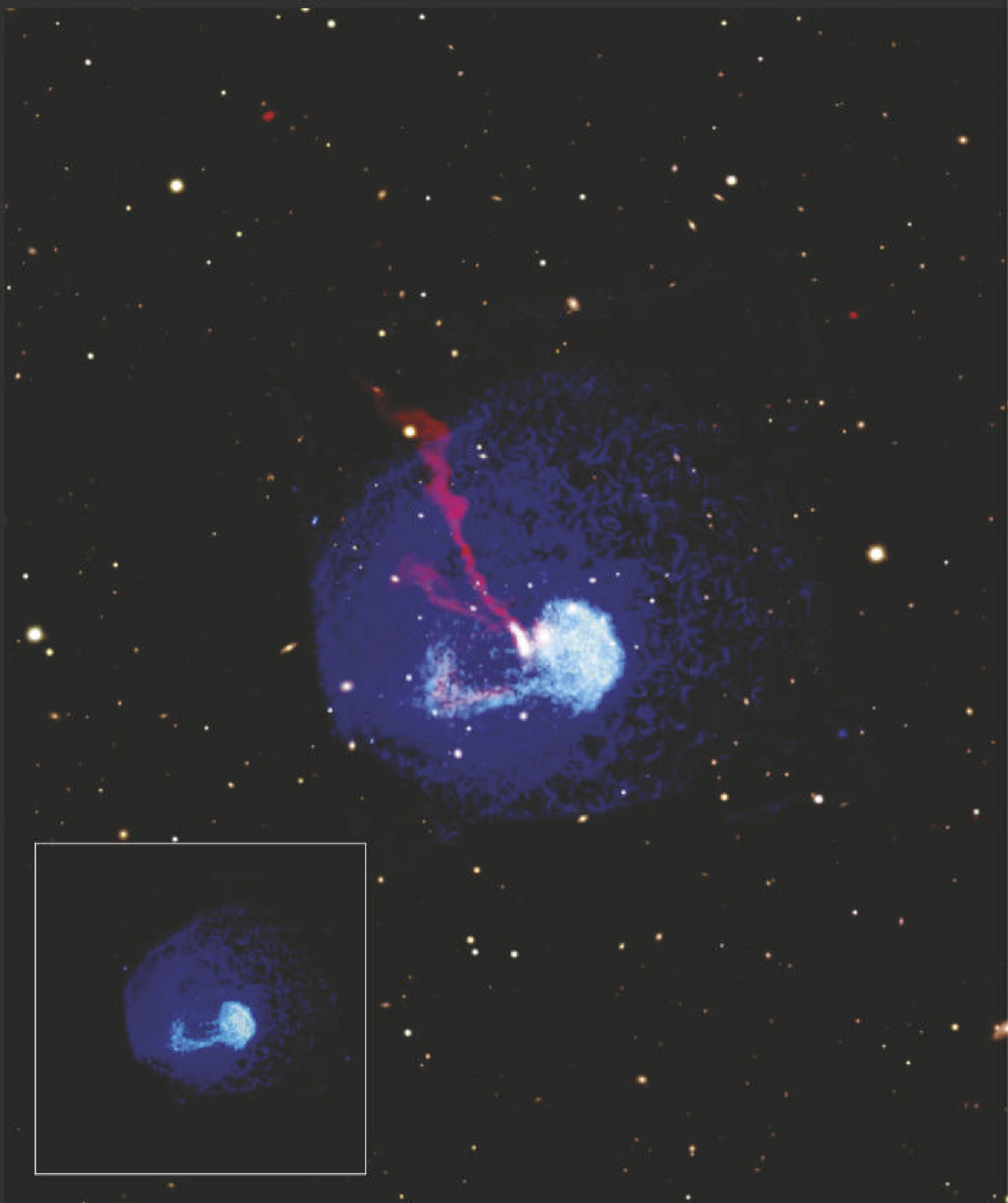
MORE **ONLINE**
A gallery of these and more stunning space images

ESO/J. EMERSON/VISTA ACKNOWLEDGMENT: CAMBRIDGE ASTRONOMICAL SURVEY UNIT

△ Virgin berth

VSS UNITY, 11 JULY 2021

Whether he officially reached space or not (NASA, which defines it as 80km, would say yes), 70-year-old Sir Richard Branson has won the 'billionaire space race', becoming the first to head skywards in his own craft. The VSS Unity rocket plane, carried part of the way by mothership VMS Eve, propelled him and five others to 86.1km above Earth, where they experienced four minutes of weightlessness. A major step towards his plans to put suborbital spaceflight within the reach of anyone with a spare $250,000, it pipped Jeff Bezos's New Shepard launch by nine days.



Slingshot or slosh? ▷

CHANDRA X-RAY OBSERVATORY/PAN-STARRS/ LOFAR, 15 JULY 2021

A titanic clash between two galaxy clusters, each containing hundreds of galaxies, has produced an unusual effect in Abell 1775. X-ray, optical and radio observations reveal an enormous pink jet from a supermassive black hole, a fainter filament below it and – clearly shown by the X-ray data (inset) – a spiralling L-shaped plume. This is the curved tail of hot gas stripped from the smaller cluster by the bruising encounter, which is thought either to have overshot the collision and 'slingshotted' to the side, or is 'sloshing' back and forth in the gravitational tussle.

VIRGIN GALACTIC/HANDOUT/ANADOLU AGENCY, X-RAY: NASA/CXC/LEIDEN UNIV./A. BOTTEON ET AL./RADIO: LOFAR/ ASTRON/OPTICAL/IR:PANSTARRS, ESO/PHANGS, COURTESY OF NASA/SDO AND THE AIA/EVE AND HMI SCIENCE TEAMS

MUSE looks for clues ▷

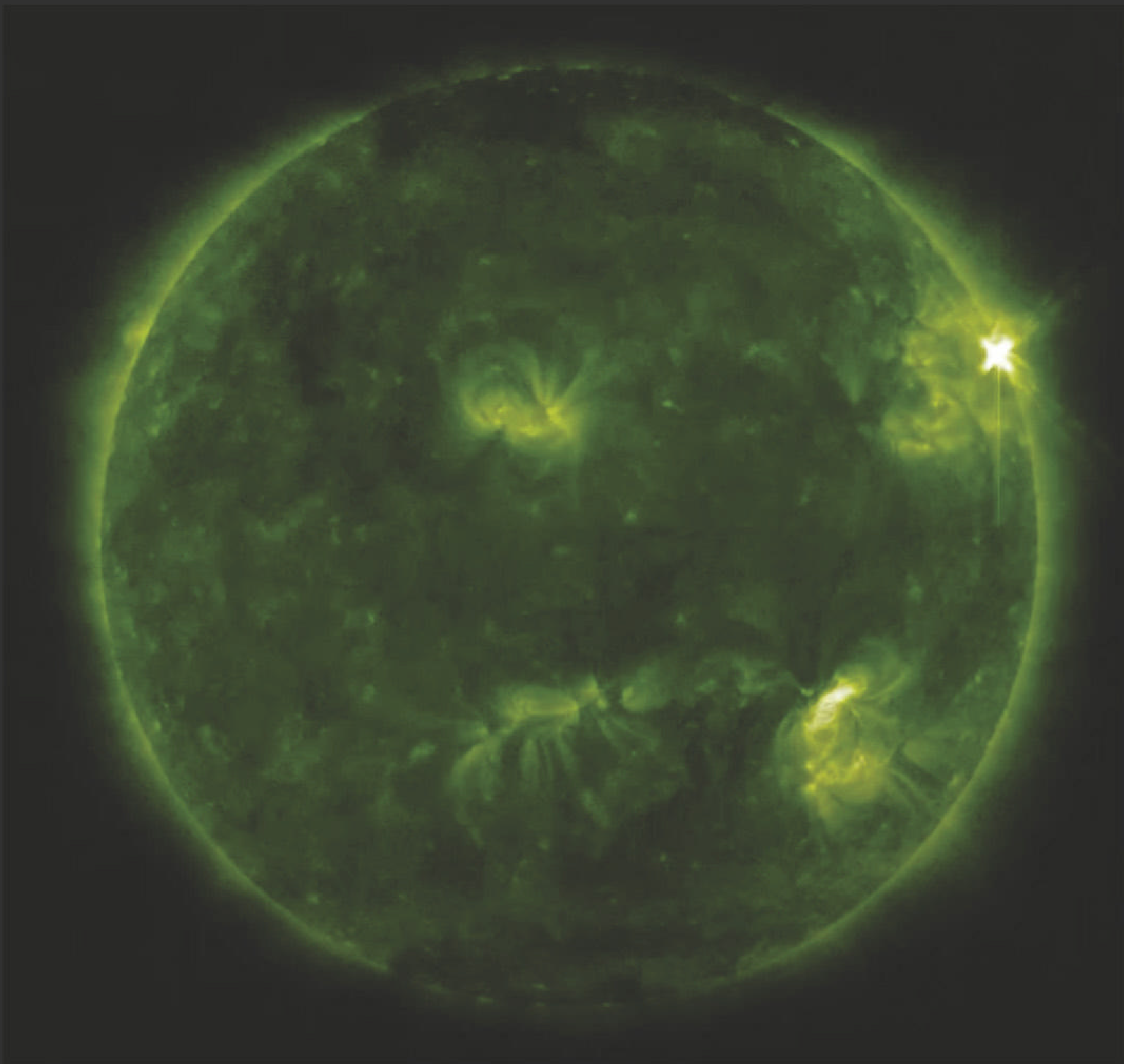
VERY LARGE TELESCOPE, 16 JULY 2021

Swirls of glowing red hydrogen reveal the regions where new stars are being minted in spiral galaxy NGC 4254. This is one of 30,000 clouds of warm gas examined by the MUSE (Multi Unit Spectroscopic Explorer) instrument attached to Chile's VLT as part of the PHANGS project, an international push to discover what triggers, and what holds back, new star formation.

▽ Flares are back

SOLAR DYNAMICS OBSERVATORY, 3 JULY 2021

SDO has spotted its first X-class flare of the new solar cycle; these are the biggest class of flare and by far the largest explosions in the Solar System. The smaller classes are A, B, C and M, each letter representing a 10-fold increase in energy output over the last. Several B- and C- and one M-class flare were spotted around the same time, with many more expected as Solar Cycle 25 builds towards solar maximum (predicted in 2025).



The latest astronomy and space news, written by Ezzy Pearson

BULLETIN

One of the first images captured by Hubble (inset) after its recent repairs was of ARP-MADORE 0002-503, a large spiral galaxy located 490 million lightyears away

Hubble resumes its observations

NASA recalled Hubble's original builders to help fix the problem

After spending five weeks offline, the 31-year-old Hubble Space Telescope is back in action and observing the cosmos.

"I'm thrilled to see that Hubble has its eye back on the Universe, once again capturing the kind of images that have intrigued and inspired us for decades," says NASA administrator Bill Nelson. "This is a moment to celebrate the success of a team truly dedicated to the mission."

A problem with the telescope's payload computer, which controls the science instruments, placed the telescope into safe mode on 13 June. Initial attempts to restart the system and switch to a backup failed. To continue troubleshooting the problem, NASA called in retired staff members who had helped build the space telescope in the 1980s and combed through 40-year-old documents by hand, attempting to uncover the solution to Hubble's malady.

"That's one of the benefits of a program that's been running for over 30 years: the incredible amount of experience and expertise," says Nzinga Tull from Goddard Space Flight Center, who led the recovery efforts. "There's so much dedication to their fellow Hubble teammates, the observatory and the science Hubble is famous for."

By mid-July, the team had identified that the problem lay in the power control unit (PCU). A protection circuit had triggered – either due to degradation or the PCU drawing the wrong voltage – and turned off the power. On 15 July, the team was able to switch over to a back-up PCU and by 17 July, Hubble was back in business, making scientific observations once again.
hubblesite.org

Comment
by Chris Lintott

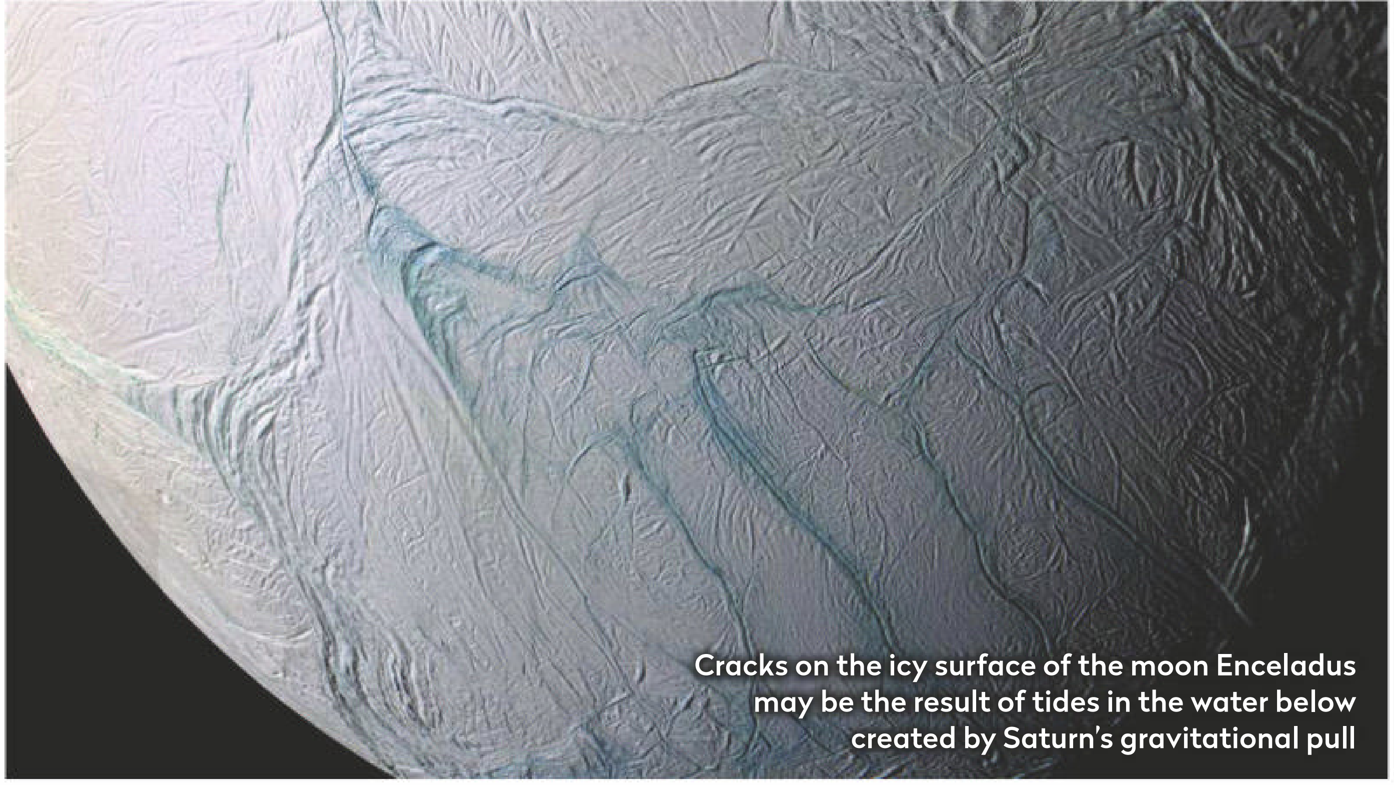
The first images taken with Hubble's restored cameras were of two unusual galaxies, as part of a survey of irregular systems led by Julianne Dalcanton.

Earlier this year observations made with Hubble revealed the surprising extent of Andromeda's gaseous halo and that quasars have been captured in its deep fields. Closer to home, planetary nebulae and stars have been scrutinised by the space telescope.

This variety is why everyone is so relieved to have Hubble back. It's a supremely multipurpose instrument, as capable of contributing to cosmology as astrobiology. Let's hope there's plenty more life in the old scope yet.

Chris Lintott co-presents *The Sky at Night*

NASA/ESA/STSCI/JULIANNE DALCANTON (UW) IMAGE PROCESSING: ALYSSA PAGAN (STSCI), NASA/JPL/SPACE SCIENCE INSTITUTE, ALMA (ESO/NAOJ/NRAO)/BENISTY ET AL, ESA/ATG MEDIALAB



Cracks on the icy surface of the moon Enceladus may be the result of tides in the water below created by Saturn's gravitational pull

Enceladus shakes with 'icequakes'

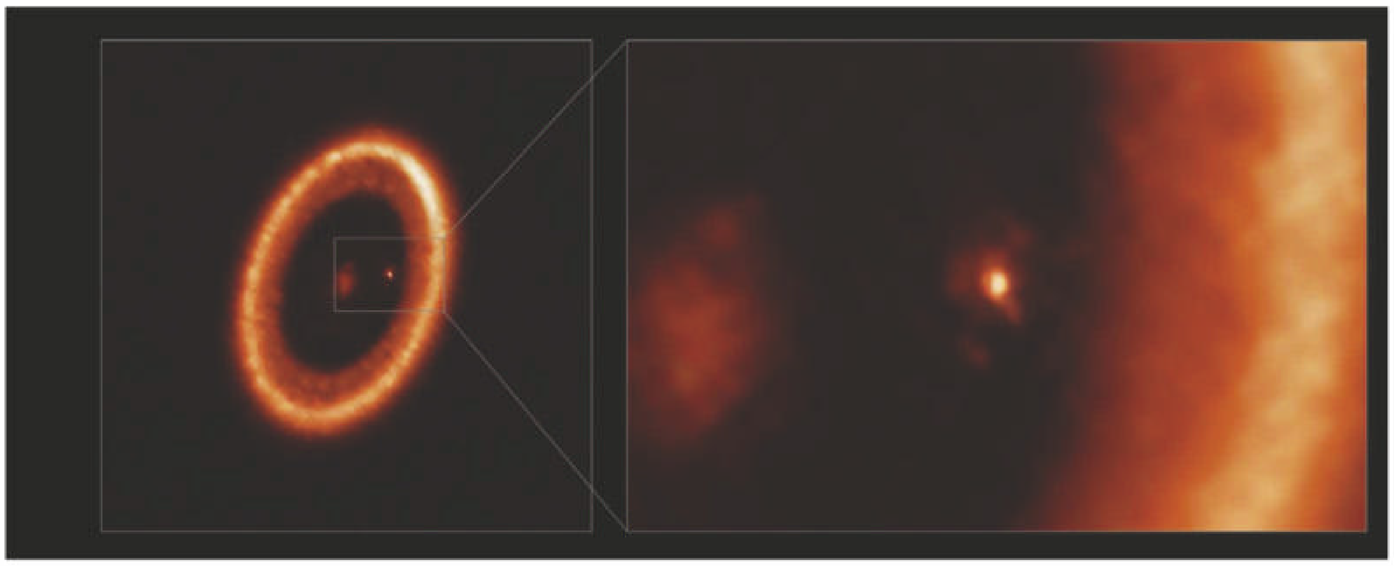
Cracks in the moon's surface could hint at what's beneath

Icequakes could rumble across the surface of icy moon Enceladus, created by the tidal forces of Saturn's gravitational pull. The hypothesis comes from a recently published study that compared stress fractures seen on the moon of Saturn with similar features found on Earth in the Ross Ice Shelf in Antarctica.

"The study represents a key way of investigating what seismicity on Enceladus and other tidally activated icy worlds may look like, by looking at the best analogues we can find on Earth," says Mark Panning from the Jet Propulsion Laboratory.

Examining the seismic profiles of a world offers an insight into its internal structure: in the case of Enceladus whether it has a subsurface liquid water ocean – an environment that could be habitable. Such icequakes could also create cracks large enough for subsurface water to escape, creating the water jets that have been seen erupting through Enceladus's icy crust.
www.jpl.nasa.gov

Moon nursery seen clearly for the first time



▲ **The disc around exoplanet PDS 70c has enough material to form three Moon-sized satellites**

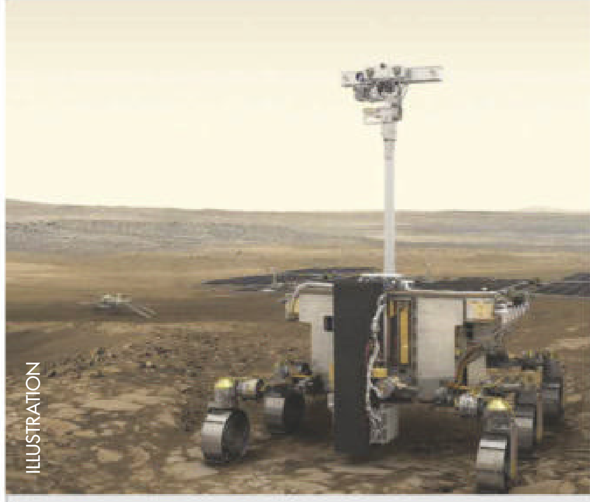
The first clear detection of a potential moon-forming disc around an exoplanet has been made by the Atacama Large Millimeter/submillimeter Array (ALMA). The disc is around the Jupiter-like planet PDS 70c and has enough mass to create three moons, each with the same mass as Earth's Moon.

Astronomers have long thought that newly formed planets are surrounded by swirling discs of material that can go on to form moons, but have struggled to differentiate them from the larger dust discs that create the planets.

"Our work presents a clear detection of a disc in which satellites could be forming," says Myriam Benisty, an astronomer from the University of Grenoble who led the study. "Our ALMA observations were obtained at such exquisite resolution that we could clearly identify that the disc is associated with the planet and we are able to constrain its size for the first time."

Though over 4,000 exoplanets have now been found, almost all of them are mature systems. The discovery of infant systems will help astronomers learn how these planets and their moons grow.
www.almaobservatory.org

NEWS IN BRIEF



ILLUSTRATION

ESA rover ready

An upgraded parachute to enable the British-built Rosalind Franklin rover to land safely on Mars has passed its high-altitude tests, meaning the rover should be ready for launch in 2022. Problems with the original 35m-wide parachutes caused a delay.

Alien artefact search

A group of astronomers have announced a new endeavour, the Galileo Project, to hunt for extra-terrestrial technological civilisations (ETCs). The project will search for physical artefacts from ETCs, including interstellar objects, such as 'Oumuamua which passed through the Solar System in 2017.

Gamma ray burst fires on queue

An unusual type of star, known as a gamma repeater, emitted its first burst after three months of inactivity on 24 June, as predicted. If it follows the pattern seen so far, the star (SGR 1935+2154) will emit random bursts for the next four months, as astronomers attempt to study the phenomenon.

▲ Richard Branson (top left), Virgin Galactic's Sirisha Bandla (above) and Jeff Bezos (top right) enjoy the views at the edge of space

Space tourism takes flight

The passenger flights captured the world's attention, garnering both praise and criticism

The billionaire founders of spaceflight companies Blue Origin and Virgin Galactic flew on board their spacecrafts' inaugural passenger flights this July, heralding a new age of space tourism.

Jeff Bezos, founder of spaceflight company Blue Origin, announced in June that he planned to fly on his company's suborbital crew vehicle, New Shepard, on 20 July. This spurred Virgin Galactic founder Richard Branson to move the first passenger flight of his own space tourism vehicle, SpaceShipTwo, forward to 11 July, ahead of Bezos.

Passengers on both flights experienced four minutes of weightlessness and a spectacular view of Earth curving away below, but the flights themselves were very different. Branson, accompanied by three other members of the Virgin Galactic team, experienced a two-and-a-half-hour flight that used a combination of conventional jet and rocket engines to reach a height of 86km.

"To all you kids down there, I was once a child with a dream looking up to the stars," Branson said during his flight. "Now I'm an adult in a spaceship with lots of other wonderful adults looking down to our beautiful, beautiful Earth. To the next generation of dreamers, if we can do this, just imagine what you can do."

Nine days later, Jeff Bezos blasted off on a rocket-powered flight that lasted just over 10 minutes, reaching an altitude of 107km. He was joined by 82-year-old aviation pioneer Wally Funk and 18-year-old Oliver Daemen, whose father spent several million dollars on the ticket. Funk and Daemen are now the oldest and youngest people to have flown in space respectively.

"When you look out at the planet, there are no borders. There's nothing. It's one planet and we share it, and it's fragile," Bezos said, after returning to Earth.

A few weeks later, Bezos announced Blue Origin was willing to cover up to $2bn of the cost of building a second Human Landing System (HLS) for NASA's future lunar missions, allowing Blue Origin to compete with one already commissioned from Elon Musk's company SpaceX.

Although the pair of passenger flights mark a pivotal moment in commercial spaceflight, they have also drawn criticism. "It's a momentous day in the history of having way too much money… for the second time in nine days a billionaire took a joy ride to the ionosphere," said comedian Stephen Colbert.

www.virgingalactic.com
www.blueorigin.com

VIRGIN GALACTIC, BLUE ORIGIN, GL ARCHIVE/ALAMY STOCK PHOTO, NASA/GODDARD SPACE FLIGHT CENTER, GIUSEPPE PARISI

Women's continuing contributions to astronomy will be celebrated by the Royal Astronomy Society's new medal, named after Caroline Herschel

RAS medal honours women astronomers

The award will alternate between the UK and Germany

A new award, the Caroline Herschel Medal, has been created to recognise the outstanding work of female astrophysicists. In honour of the medal's namesake, who was German-born but lived in Bath, the medal will be awarded to a UK astronomer one year, and a German astronomer the next.

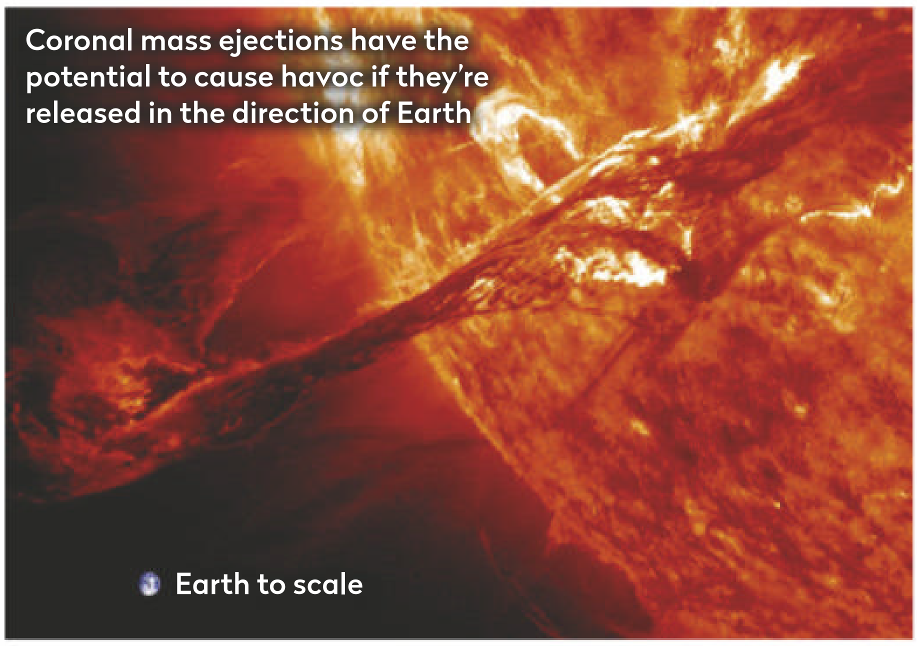
Astronomy is currently a male-dominated field: only 27 per cent of astronomy lecturers and 12 per cent of professors are female. It is hoped that the award will redress this balance by increasing the visibility of women in astronomy.

"Caroline Herschel has a profound connection to our Society and had a significant impact on astronomy, and as such it is fitting that a new medal and prize should be named in her honour," says Emma Bunce, president of the Royal Astronomical Society, who created the medal alongside the German Astronomical Society.

ras.ac.uk

Solar Orbiter spots secret Sun storms

Astronomers can now predict the path of 'stealthy' solar storms, with the help of ESA's Solar Orbiter. Coronal mass ejections (CMEs) are huge solar eruptions that eject particles and radiation. If one hits Earth, it can damage power systems and satellites, though these effects can be mitigated if we know one is coming. CMEs that originate near the Sun's equator form dark and bright patches on the solar surface, but at higher latitudes they are only visible using a special instrument called a coronagraph.



Coronal mass ejections have the potential to cause havoc if they're released in the direction of Earth

"If you see a CME on a coronagraph, you don't know where on the Sun it came from, so you can't predict its trajectory and won't know whether it will hit Earth until it's too late," says Erika Palmerio from the University of California at Berkeley, who led the study.

To remedy the problem Palmerio's team looked at images from the Solar Orbiter, which launched in 2020. This revealed a pattern of tiny variations that had been invisible to previous observatories, but which could help astronomers track the origin of CMEs.

www.esa.int

NEWS IN BRIEF

Living on the edge

The smallest, yet most massive white dwarf ever observed has been found, packing 1.35 times the mass of our Sun into an object the size of the Moon. The star probably formed when two smaller white dwarfs merged, and is right on the limit of how massive such a star can be before going supernova.

Cosmic wanderers

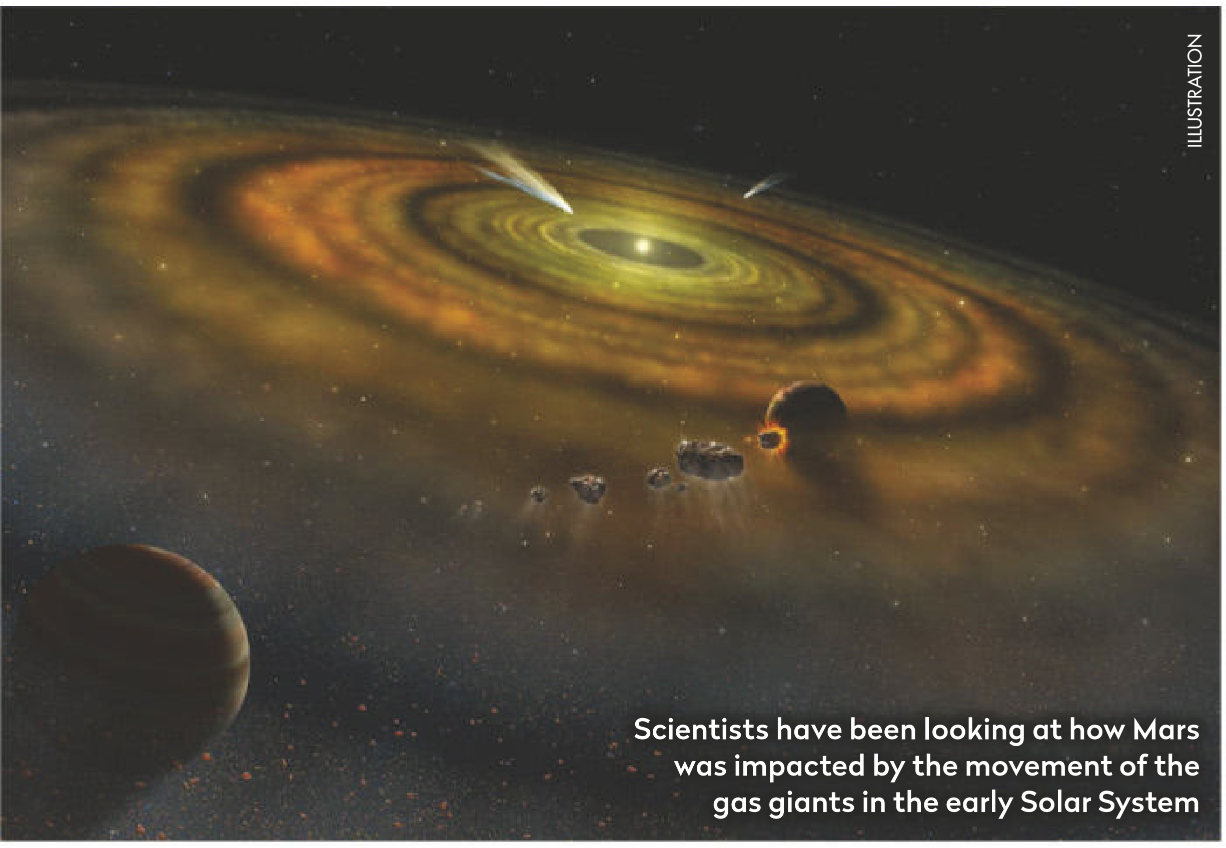
The Kepler Space Telescope has revealed four new free-floating planets, untethered from a host star. The telescope found them by looking at the same star field every 30 minutes for two months, hunting for microlensing signals – where starlight is bent as it passes by a planet.

Module misses ISS

Nauka, the Russian science module for the ISS finally launched on 21 July, over a decade behind schedule, only for a suspected computer fault to prevent it docking. As of writing, flight controllers were still hopeful the module would be able to rendezvous with the ISS at a later date.

Our experts examine the hottest new research

CUTTING EDGE



Scientists have been looking at how Mars was impacted by the movement of the gas giants in the early Solar System

Did planetary migration stunt Mars's growth?

The movement of planets in the early Solar System could have starved infant Mars

We know the Solar System formed about 4.5 billion years ago from a disc of dense gas and dust swirling around the proto-Sun. The gas giant planets formed rapidly in the cooler, outer region of this protoplanetary disc, while the rocky inner planets finished accreting sometime later. What has become increasingly clear over recent years, however, is that the initial configuration of the primordial Solar System was very different, and at some point the gas giant planets shifted and migrated into their current orbits. This period of 'dynamic instability' would have been hugely disruptive to the entire system. For example, the current best-supported model argues that our planetary system actually formed with one or two additional ice giants (alongside Uranus and Neptune), which were subsequently ejected out of the Solar System.

But we still seem to be missing something important in our understanding of the formation of the planets. Many models commonly produce a fourth planet that is about 10 times more massive than Mars, and also a massive planet in the asteroid belt. There's clearly something wrong here.

NASA, NASA/SAO/CXC/C.JONES ET AL.

Gas giants on the rampage

Matthew Clement at the Carnegie Institution for Science, Washington, DC, and his colleagues argue that the important detail is when this dynamic instability arose. Over the past few years they have performed a series of studies that indicate the Solar System was thrown into turmoil very early in its history. Clement's models work with Jupiter and Saturn going on the rampage within the first 100 million years after the Sun's birth and even before the final assembly of the rocky inner planets. In this latest study they have run some updated computer models of this early instability scenario for the formation of the planets. This time they have been focusing specifically on how sensitive the outcome for Earth and Mars is to shifts in Jupiter and Saturn's orbits.

They found that such an early instability in the orbital architecture of their modelled Solar Systems invariably truncated the terrestrial disc beyond the Earth-forming region. This stunted the growth of Mars, producing a planet much like the one we find. The early instability also prevented the formation of a large planet between Mars and Jupiter, leaving a suitably depleted asteroid belt. What's more, in many of Clement's model Solar Systems, the simulated Earth ended up colliding with another massive protoplanet – just as is believed to have happened to form the Moon.

"The models work with Jupiter and Saturn going on the rampage within the first 100 million years after the Sun's birth"

Clement stresses, however, that this is by no means the final word on how the Solar System was originally formed. These updated models explain a lot that was previously problematic, but they leave some unanswered questions. For example, these models still struggle to reproduce the low orbital eccentricities of Earth and Venus. The creation of an innermost planet like Mercury is also difficult. These shortcomings, says Clement, are outstanding problems that future planet formation studies will need to resolve.

Prof Lewis Dartnell is an astrobiologist at the University of Westminster

Lewis Dartnell was reading... *The Early Instability Scenario: Mars' Mass Explained by Jupiter's Orbit* by Matthew S Clement et al
Read it online at: https://arxiv.org/abs/2106.05276.

An X-ray view of the Virgo Cluster

A look at what lies beyond the visible can reveal a galaxy's hidden secrets

Prof Chris Lintott is an astrophysicist and co-presenter on *The Sky at Night*

Most elliptical galaxies aren't much to look at, not much more than a rounded ball of stars. Wide-field images of the Virgo Cluster, a nearby home for many ellipticals, add interest by showing the sheer number of systems, but each individually is, well, pretty dull. This is, of course, appalling bias, typical of a species (Homo sapiens) from a spiral galaxy which happens to see with eyes sensitive only to wavelengths that cover 4,000 to 7,000 Ångstroms. Look at these systems with X-ray eyes – or, as Harvard's Nazma Islam and colleagues do, rummage through the archives of the XMM-Newton space telescope – and they look different, with dramatic jets and hot gas swirling around the brightly glowing black holes at their centres.

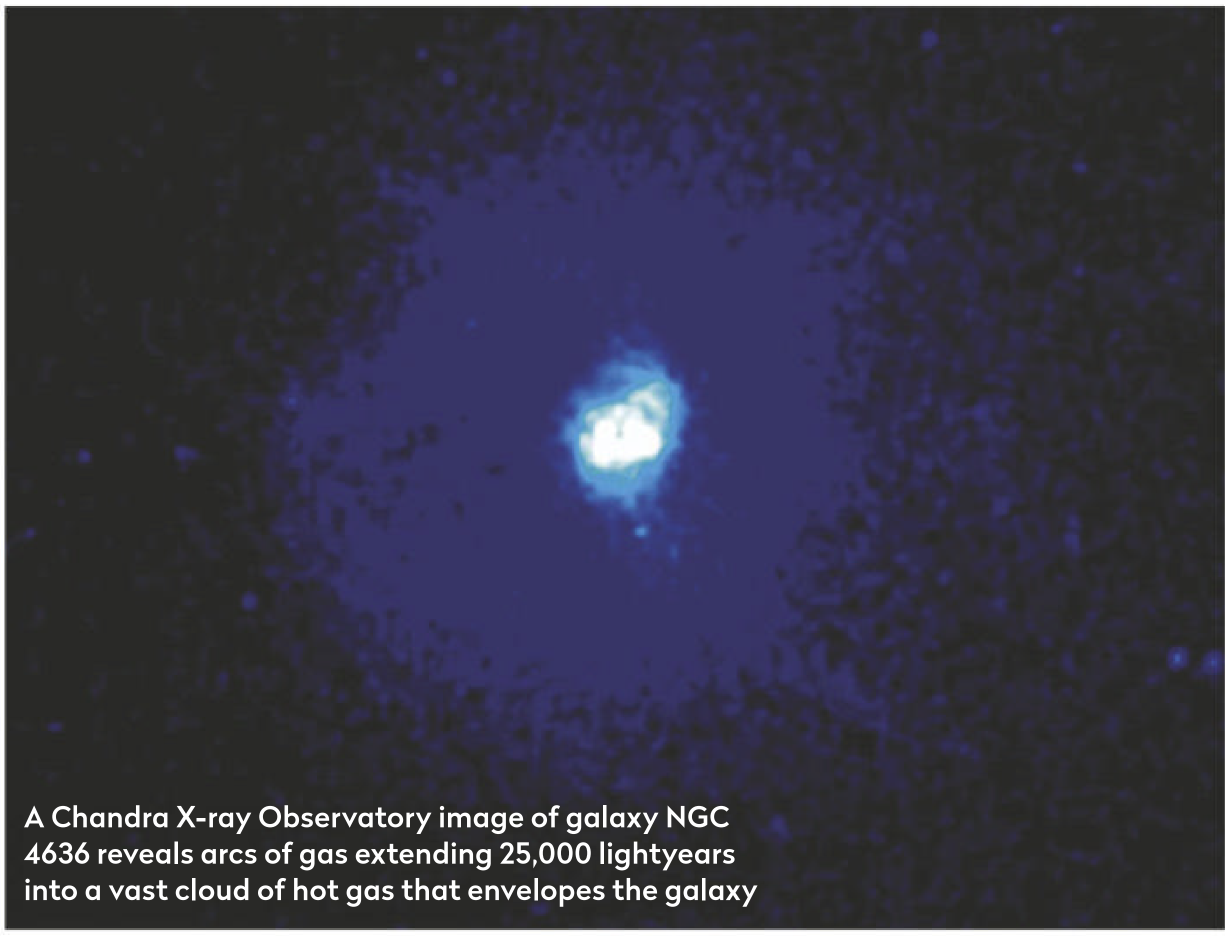
The team has assembled an atlas of such observations (there is a long-standing astronomical tradition of using 'atlas' to mean not a book of maps, but a collection of images). The galaxies included have already featured in a similar collection of observations with NASA's Chandra X-ray Observatory, but XMM is a larger telescope, operating at slightly shorter wavelengths, and Chandra has a smaller field of view than its European counterpart. While the Chandra observations told astronomers a lot about what was happening to the galaxy itself, a broader perspective is needed to understand how the systems interact with their surroundings. As hot gas expelled from galaxies can alter the environment of neighbouring galaxies, or even affect them directly, this is important.

Take NGC 1550, for example. The Chandra image shows a nice, smooth halo of hot gas throughout most of the galaxy, but XMM confirms the presence of a bar-like feature at the galaxy's nucleus, aligned roughly east to west. From observations of the galaxy's spectrum, we can tell this east to west feature is formed of cooler gas, and it seems to line up with jets that others have seen in radio observation. The jets come from activity associated with the galaxy's central supermassive black hole, and they appear to have captured cooler gas associated with stars in the inner regions of the system, carrying it out into the galaxy.

"As hot gas expelled from galaxies can alter the environment of neighbouring galaxies, or even affect them directly, this is important"

The other galaxy considered in detail, NGC 4636, shows what can happen when these processes happen on a large scale. Here, gas is being expelled from the galaxy altogether, shocking material in the intergalactic medium and heating it up so it glows brightly in the XMM image. The observations also reveal the metallicity of the gas – the proportion of elements heavier than hydrogen and helium, which, as they are produced by previous generation of stars, provide a guide to how processed by star formation the gas has been.

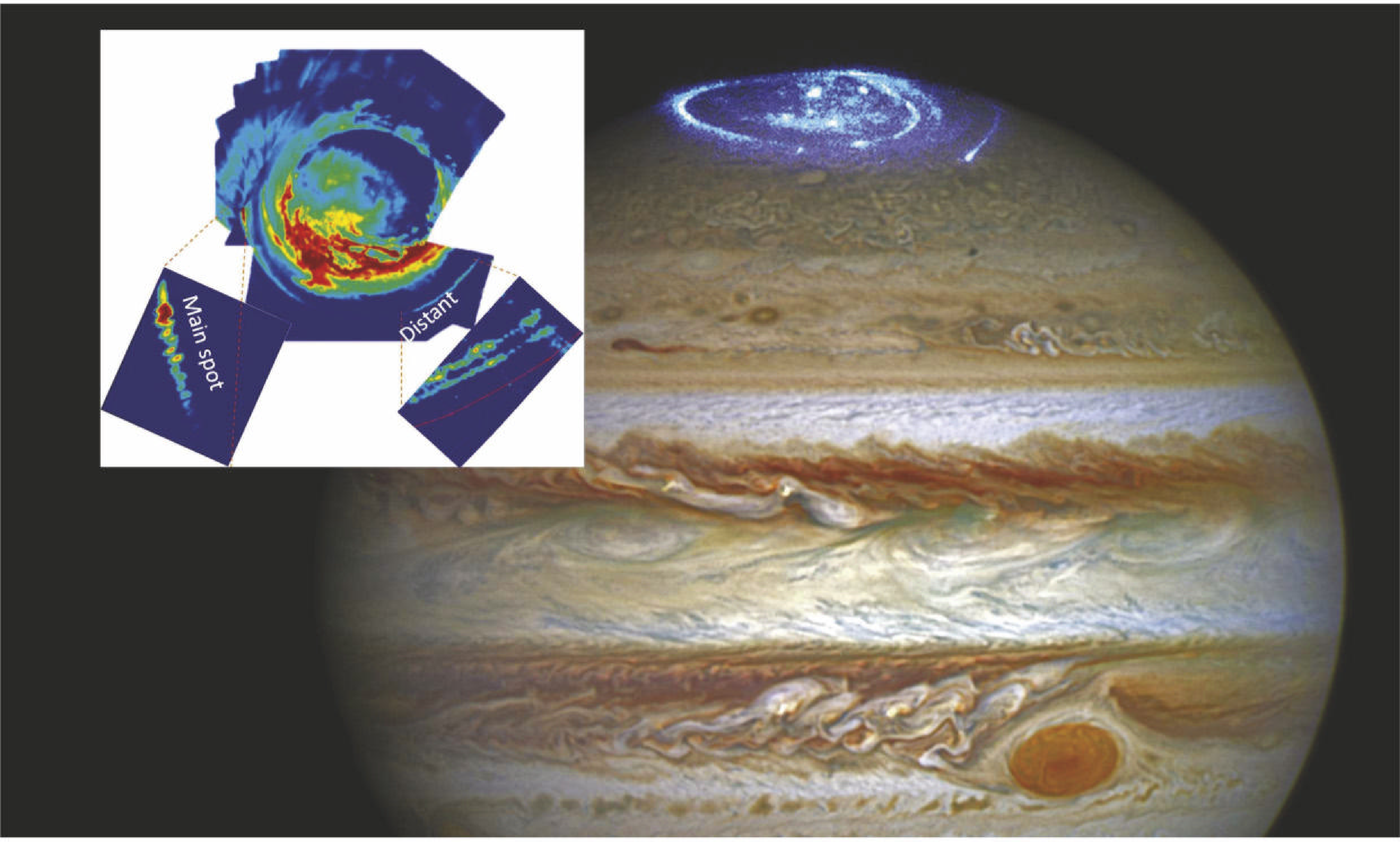
Each of the other 36 galaxies will have their own stories to tell. This kind of work in the archives, which reflects a huge amount of effort to reprocess and display archived data in a uniform and useful fashion, doesn't always get enough attention, but catalogues like these are the raw materials for future science – and it's also sometimes just fun to look at pictures of galaxies, especially when you pick the right wavelength.



A Chandra X-ray Observatory image of galaxy NGC 4636 reveals arcs of gas extending 25,000 lightyears into a vast cloud of hot gas that envelopes the galaxy

Chris Lintott was reading... *An XMM-Newton Early-type Galaxy Atlas* by Nazma Islam et al..
Read it online at: https://arxiv.org/abs/2106.14937

INSIDE THE SKY AT NIGHT



▲ **Scientists are learning about Jupiter's aurorae, by combining the observations taken by the Hubble Space Telescope with the top-down views (inset) taken by the Juno mission**

In August's *Sky at Night* episode, **Jonathan Nichols** reflects on his work with Juno, which has just had its mission extended by four years

Five years ago, I had the privilege to stand in the Rose Bowl stadium in Pasadena, California, and pose for a photo with members of the NASA Juno mission science and engineering teams just hours before the spacecraft was due to enter into orbit around Jupiter. The atmosphere in the Jet Propulsion Laboratory later that evening was thick with tension as we awaited the signal that the spacecraft had fired its engine correctly. After a five-year journey, we were poised to find out if the mission that had been years in the planning would take place – or not.

As we now know, the main engine, built by the British company Moog UK Westcott, fired perfectly, and cheers of joy greeted the start of what has turned out to be an astonishing journey of exploration.

Juno's principal science goal is to peer beneath Jupiter's clouds and reveal the secrets of the planet's interior and the story of its formation, and by extension that of the rest of the Solar System. But its unique orbit passing over the poles has particular value for my field of research – the study of the magnetospheres of the outer planets. Like Earth, the outer planets possess magnetic fields which create spectacular auroral emissions. For over 10 years I had observed Jupiter's aurorae from afar with the Hubble Space Telescope, and now we were to get a birds-eye view from above the auroral zone. The pictures were stunning; the science team cheered and clapped when the first images of Jupiter's infrared aurorae from the Jovian Infrared Auroral Mapper (JIRAM) instrument were shown at a meeting: intricate swirls, arcs and blobs of aurora that were hitherto unseen.

NASA/ESA AND J. NICHOLS (UNIVERSITY OF LEICESTER) X 2, GRANGER HISTORICAL PICTURE ARCHIVE/ALAMY STOCK PHOTO, BBC

THE SKY AT NIGHT WANTS YOUR QUESTIONS

As part of the British Science Festival 2021, *The Sky at Night* is recording a special programme on 8 September, when the presenters and special guests will be answering questions from viewers. If you have a question – on anything from space travel and technology to astronomy and astrophysics – you can email it to the programme team at: skyatnightqt@bbc.co.uk

Jonathan Nichols, is a Reader at the University of Leicester, and member of the Juno Science Team

A surprise was the form of the Io auroral footprint, which is a manifestation of the electromagnetic interaction between the rapidly rotating Jupiter and its innermost Galilean moon. The volcanoes of the little moon spew sulphur and oxygen into space, much of which is picked up by Jupiter's rotating magnetic field and propelled away from the planet to form a rotating disc of plasma surrounding the gas giant.

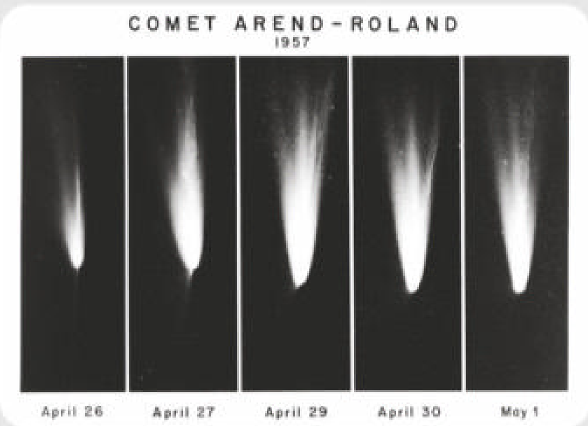
The electromagnetic tug of war between Jupiter and the plasma disc, mediated by millions of amps of electric current, has long been thought responsible for Jupiter's bright main ring of aurora. However, surprisingly, the signatures of this electric current were not reported in the first results from over the auroral region, leading to a debate as to what actually drives Jupiter's main auroral emissions. More recently, by using a combination of Hubble and Juno data we have shown that the electric currents in the magnetosphere are increased when the aurorae are bright, which, in my view, strongly implicates the tug of war is powering the emissions.

But Juno's journey is still underway and has years yet to run. It will be exciting to see the results as Juno progresses around to the dusk side of Jupiter's magnetosphere, which will provide vital information about the processes which drive Jupiter's aurorae.

Looking back: The Sky at Night

19 September 1957

On 19 September 1957, Patrick Moore was joined on *The Sky at Night* by 15-year-old Clive Hare, who had been the first person in the UK to spot a new bright comet – Comet Mrkos.



▲ **Comet Arend-Roland, as viewed with a 48" Schmidt-Cassegrain telescope in 1957**

In April and May 1957, Comet Arend-Roland – the first naked-eye comet in several decades – had been streaming across the night sky. Now faded from view, astronomers assumed there would be a long wait for the next.

But then, just a few months later on the morning of 29 July 1957, Japanese astronomer Sukehiro Kuragano spotted what appeared to be another comet streaming across the sky. A few days afterwards pilot Peter Cherbak also spotted the same object while flying over Nebraska. Unfortunately, both were delayed from reporting their discoveries and so the credit instead went to Antonín Mrkos from then-Czechoslovakia, who spotted the comet on 2 August and sent out an Astronomical Telegram to inform the community. The next day, British schoolboy Clive Hare also spotted the comet in a telescope he'd built himself, but, alas, was too late to claim the discovery.

The reason for so many independent sightings was that Comet Mrkos, as it became known, approached from such an angle that it was hidden as it approached the Sun. It was only when it passed the Sun that it could be seen, by which point it was already a bright and fully active comet.

The Sky at Night SEPTEMBER

Sky at Night: Question Time

This month's episode is a one-hour special filmed live from the Civic Theatre in Chelmsford as part of the 2021 British Science Festival. Maggie, Chris, Pete and a panel of special guests and astronomy experts take to the stage in front of a studio audience to answer questions about the mysteries of the Universe and provide practical observing advice.

BBC Four, **12 September**, 10pm (first repeat BBC Four, **16 September**, 7:30pm)
Check www.bbc.co.uk/skyatnight for more up-to-date information

▲ **Maggie, Chris and the panel on stage during *Sky at Night* Question Time in 2019**

Emails – Letters – Tweets – Facebook – Instagram – Kit questions

INTERACTIVE

Email us at **inbox@skyatnightmagazine.com**

This month's top prize: two Philip's titles

PHILIP'S The 'Message of the Month' writer will receive a bundle of two top titles courtesy of astronomy publisher Philip's: Heather Couper and Nigel Henbest's *2021 Stargazing* and Robin Scagell's *Guide to the Northern Constellations*

Winner's details will be passed on to Octopus Publishing to fulfil the prize

MESSAGE OF THE MONTH

Inspired by the gas giants

About two years, while on a night shift, one of my colleagues showed me two dots in the sky, which turned out to be Jupiter and Saturn. At that moment I realised how much is actually in the night sky and that inspired me to see what else was out there.

A few weeks later I bought my first telescope and I got hooked on stargazing after looking at the Moon. (It also made me look into many of the space missions, including Apollo, Voyager and Cassini.) It amazes me that something so far away can be seen so large and in so much detail; it really puts into perspective how small we are and how far away everything is.

I can't wait until Jupiter and Saturn come back around so I can take photos of them.

Jamie Addison, via email

Inspiring words, Jamie! There's nothing like seeing the largest planets in the Solar System to bring home the true size of the cosmos we inhabit. We can't wait for them to be better placed either. ***– Ed***

▲ **Jamie's photo of the Moon, showing the crater Copernicus and Montes Apenninus, as taken with a Samsung Galaxy S10+ through an eyepiece**

Tweet

Lar McCarthy
@parsec98 • 19 Jul
The Dumbbell Nebula, M27, taken from my backyard #observatory in #Cork #Ireland with a @Celestron C11 CGEM and a @zwoasi 1600MM Pro Cool through Ha and OIII filters. @CorkAstronomy @ AstronomyIRL @AstronomyMag @skyatnightmag

DAILY HERALD ARCHIVE/CONTRIBUTOR/ISTOCK/GETTY IMAGES, RODW/WIKIPEDIA/PUBLIC DOMAIN

Different views

I'm no scientist but two articles in the July 2021 issue appear to contradict each other. On page 9 in 'Eye on the Sky' the 'We're nothing special' caption states that observations of spiral galaxies like our own lead scientists to conclude that the Milky Way, "...evolved peacefully over eons," and "...didn't come about because of a gigantic mash-up." But on page 11 in 'Bulletin', the 'Stolen stars' story explains that several of the oldest giant red stars in our Galaxy "...originally belonged to a satellite galaxy called Gaia-Enceladus, which collided with the Milky Way billions of years ago." How are these contradictory conclusions both correct?

Georgina Gittins, via email

The two pieces of research that we reported on do appear to contradict each other. Indeed, this is the nature of astronomy as a science, where there is not a final definitive answer, but rather a most widely accepted explanation for the current observations, until more detailed observations come along. In this case the Gaia-Enceladus Milky Way collision is currently the more widely accepted theory. ***– Ed.***

Following the ISS

My name is Billy Herbert and I'm 13 years old. On Sunday 18 July I watched the International Space Station pass over our home with my dad and brother Gavin, which was fantastic with clear skies. Then on Wednesday the 21st at 10:01pm we observed the space station again, but this time it was followed by two other satellites showing the same amount of light as the space station, looking from

the ground like they were about 100 to 200 metres apart, going across the sky on the same line until they disappeared. The last time we checked, on Thursday 22nd at 22:59pm, the following satellites were not there with the space station. Do you know what they were?
Billy Herbert, Whitchurch, Hampshire

Well observed, Billy! It's likely the following satellites were the Russian Nauka laboratory module, which has an 11m-long robotic arm on its outside. Nauka launched on 21 July to dock with the space station on the 29th. *– Ed.*

Space walk

I was intrigued by Mary McIntyre's article ('Make a scale model of the Solar System', August 2021 issue). If you want to appreciate the scale of the Solar System then do the Somerset Space Walk along the Bridgwater and Taunton Canal. Stretching over 22km, the Sun and planets are represented in the correct proportions in both distance and size of models. The Sun is at the mid-point and the diameter of the ▸


The Somerset Space Walk is centred around the Sun near Maunsel Lock Tearooms

ON FACEBOOK

WE ASKED: Who or what has made the greatest contributions to astronomy?

Carol Miller For me it has to be NASA's Voyager missions. They are amazing.

Kris Derry Sir Patrick Moore, with his boundless enthusiasm and passion for the subject.

Paul Etcell Herschel... Hubble... Hoyle... Hawking... The answer is H-based...

Brian Smale Einstein and his general theory of relativity

Christopher James Heather Couper

AR Gavin Copernicus – he changed the theory about the Earth being the centre of the Universe. It could be said that he laid the foundations for modern astronomy.

SCOPE DOCTOR

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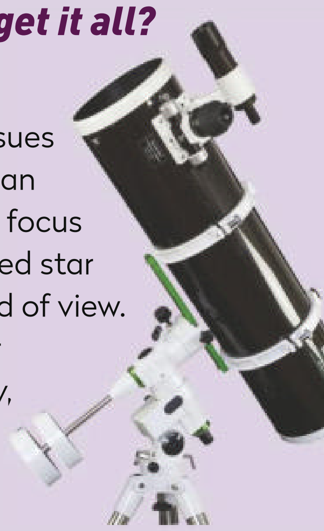
With **Steve Richards**

Email your queries to
scopedoctor@skyatnightmagazine.com

I have a Sky-Watcher 200PDS and 250PDS Newtonian reflector, and an Altair Hypercam 290C and 183C camera. I tried to take a filtered image of the Sun, but couldn't capture the whole disc. Would a focal reducer help me get it all?
COLIN ANDERSON


▲ A focal reducer is unsuitable for a Newtonian like the Sky-Watcher 200PDS

The short answer is no! There are two main issues that make using a focal reducer on a Newtonian reflector unsuitable: the difficulty in obtaining focus with a camera, and the generation of elongated star shapes towards the edge of the increased field of view.

Newtonian reflectors are renowned for their short back-focus, which makes focusing tricky, if not impossible, to achieve on some instruments as the focus tube simply cannot be moved in far enough. Your two Newtonians are DS versions, which means that the length of the optical tube has been slightly shortened and the secondary mirror moved closer to the primary mirror. This modification projects more of the light cone out through the focuser making camera focus easier to achieve. But a focal reducer would negate this advantage.

Newtonian reflectors suffer from coma which leads to the generation of elongated stars at the edge of the field of view, which is why coma correctors are often used by imagers. Unfortunately, a focal reducer would exacerbate this issue enormously, producing extremely poor shaped stars off axis.

Steve's top tip

What is an eyepiece's focal length?

An eyepiece works by adjusting its distance from a telescope's focal plane (the point at which light through the scope is focused) so that a 'pencil' of parallel light rays, known as the exit pupil, enters the pupil of the observer's eye. When the eyepiece is in focus, its focal length is the distance from the scope's focal plane to the point inside the eyepiece where the light rays become parallel thanks to being refracted by the lens elements, and it's usually in millimetres. The magnification of the telescope/eyepiece combination can be worked out by dividing the scope's focal length by the eyepiece's focal length.

Steve Richards is a keen astro imager and an astronomy equipment expert

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EDITORIAL
Editor Chris Bramley
Art Editor Steve Marsh
Production Editor Neil McKim
News Editor Ezzy Pearson
Staff Writer Iain Todd
Reviews Editor Paul Money

CONTRIBUTORS
Paul Abel, Rob Banino, Nisha Beerjeraz-Hoyle, Shaoni Bhattacharya, Jamie Carter, Lewis Dartnell, Glenn Dawes, Dave Eagle, Alastair Gunn, Annie Hogan, Tim Jardine, Pete Lawrence, Scott Levine, Chris Lintott, Mary McIntyre, Jonathan Nicholls, Steve Richards, Ian Ridpath, Govert Schilling, Hayley Smith, Steve Tonkin, Jane Williamson, Penny Wozniakiewicz

ADVERTISING SALES
Advertising Manager Andy Williams
+44 (0)117 300 8803, Andy.Williams@immediate.co.uk
Inserts Laurence Robertson +353 (0)87 690 2208

PRODUCTION
Production Director Sarah Powell
Production Coordinator Lauren Morris
Ad Services Manager Paul Thornton
Ad Coordinator Charles Thurlow
Ad Designer Parvin Sepehr
Reprographics Tony Hunt, Chris Sutch

LICENSING
Director of Licensing and Syndication
Tim Hudson
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Instagram

astrojackmn • 17 July

NGC 7000 – the North America Nebula! It feels great to have revisited the first target I ever shot and I have come away with an image that shows I have improved. I love this target as it is so large and bright and has such a distinctive shape. I'm always drawn to shooting targets that are recognisable and this is definitely one of them. @bbcskyatnightmagazine @idadarksky @skywatcheraustralia @sky_watcher_official #astrophotography #astro #ngc7000 #northamericanebula #emissionnebula #cygnus #caldwell20

▸ orbits is represented, so there are two models for each planet.
Bian Hensley, via email

Impactful names

Reading the names put forward for the resultant galaxy from the Andromeda and Milky Way merger (Cutting Edge, 'When galaxies collide', April 2021), the ones put forward are rather bad; 'Andromilky Way' is the best name.
Stuart Buchanan, via email

Could 'Impactus' be a name after the collision? Given it's a clash of Titans, 'Perseus' would have been perfect but that's taken. **William Messer, via email**

SOCIETY IN FOCUS

▲ Left to right: Dr Paul Olver (former Herefordshire AS Chairman), Mark Chamberlain (Chairman) and Christianne Wakeham (MESC organiser and Outreach Speaker)

Herefordshire Astronomical Society was established in 2008 and today has about 70 members. We hold monthly talks, observing nights from autumn to spring and organise trips, visits and local outreach events. We also host an annual Rev TW Webb lecture in honour of the famous Victorian astronomer who lived and worked in the county.

Herefordshire has some of the darkest night skies in the country and we were fortunate to be able to use Berrington Hall, a National Trust venue, when we first established our regular observing nights. We now have two other sites at the villages of Fownhope and Bartestree.

Kindle Centre in Hereford City is our main venue for talks. We've used it every month since 2008, but since March 2020 we have held our talks on Zoom due to COVID-19. This has, however, allowed us to engage speakers from further afield.

Over the years we've visited a number of astronomical venues including the National Space Centre, The Spaceguard Centre, Norman Lockyer Observatory, Hanwell Observatory and the Herschel Museum of Astronomy.

The Society has organised a number of outreach astronomical events, including the 2015 partial solar eclipse with Madley Environmental Study Centre (MESC) next to the BT International Satellite Station, which provided a guided tour of its facilities. We had clear skies for the eclipse and over 600 people attended. In July 2019 we marked the 50th anniversary of Apollo 11, again at Madley, with talks and a display of lunar rock samples.

All being well, on 9 September we will return to the Kindle Centre for a talk by Paul Haley on how observatories developed in the 19th century.

Mark Chamberlain, Chairman
Martin Stratford, Website Manager
▸ **sites.google.com/site/hsastro/home**

COVID-19
Online and socially distanced events taking place this month

We pick the best live and virtual astronomy events and resources this month

WHAT'S ON

PICK OF THE MONTH

▲ Enjoy engaging talks on subjects ranging from stargazing to folklore and cosmology

Online Brecon Beacons Virtual Dark Skies

A brand new night-sky festival comes to mid-Wales, from 24–26 September

Launching online-only this year, we expect big things for this new annual event for stargazing beginners.

Astronomer Royal Martin Rees kicks off three days of virtual talks and happenings that include award-winning physicist Paul Davies (top, right) walking us through the riddles in our Universe, and Colin Burgess (bottom, left), author of *The Greatest Adventure*, exploring the Space Race. Local astronomy expert Martin Griffiths will reveal Welsh mythology of the night sky, and there's a chance to find out about meteorites and more. Aimed at anyone (10 and up), events are via Zoom and cost £2. Book via **bit.ly/3z47yH0**.

LUKE JERRAM

Live Museum of the Moon

South West, August–December

Luke Jerram's Museum of the Moon art installation will be at Bristol Cathedral until the 30th, after which catch it at Wells Cathedral (12 October–3 November) and Bath Abbey (19 November–26 December), accompanied by Moon science, folk concerts, a talk by astronaut Helen Sharman, storytelling, crafts and more. Visit **my-moon.org**

Online Space debris

3 September, 7:30pm

What's the future for ground-based astronomy in a new era of satellite mega-constellations? asks Warwick University's Professor Don Pollacco in this talk from the Astronomical Society of Edinburgh. Visitors are welcome to watch live on the ASE's YouTube channel. **bit.ly/3ku3Dza**

Live Stargazing weekend

Otterburn, Northumberland, 3 and 4 September

Tour the Milky Way, star clusters and galaxies from a pub on the edge of the Northumberland International Dark Sky Park. With talks from experienced astronomer Richard Darn. Suitable for novices. All equipment provided; £60 per person, including B&B. **bit.ly/3exihlA**

Live Knowle meeting

Dorridge Village Hall, Solihull, 6 September, 8pm

Members and visitors are welcome to Knowle Astronomical Society's session on getting the best out of your telescope and setting it up for astrophotography. Follows the society's AGM. Contact: **KAScomm2001@gmail.com**

Live Essex stargazing

Great Notley Country Park, Braintree, 18 September, 6pm

All ages are welcome to North Essex Astronomical Society's evening, looking at the Moon, planets and other objects of interest. Free. **northessexastro.co.uk**

Live Cairngorms aurorae

Glenlivet Public Hall, Ballindalloch, 26 September, 9pm

Cairngorms Astronomy Group takes a look at how aurorae, a frequent local sight around the equinoxes, are triggered by space weather and conditions on the Sun. **www.cairngormsdarkskypark.org**

Live Astrophotography talk

Steeton Methodist Church, West Yorkshire, 23 September, 7:30pm

All are welcome to Dr Pamela Whitfield's talk, 'A Transatlantic Adventure in Astrophotography', for Keighley Astronomical Society. £3 on the door. **keighleyastronomicalsociety.co.uk**

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FIELD OF VIEW

Patchwork project for the RAS bicentennial

Annie Hogan reports on a quilt to mark the Royal Astronomical Society at 200

Annie Hogan is a space and sewing enthusiast and Membership Officer at the Royal Astronomical Society

A lot can happen in 200 years, from the discovery of Neptune and white dwarf stars to detecting gravitational waves and 'photographing' a black hole. The field of astronomy has certainly advanced in the two centuries since the Royal Astronomical Society (RAS) was founded. The Society celebrated its 200th anniversary in 2020 and one of the ways chosen to mark this milestone was by making a commemorative quilt: something tangible that our Fellows and other members could get involved with; a creative project which the Society could keep for the next one hundred years.

Inspired by Ellen Baker's 1876 Solar System quilt (currently housed at the National Museum of American History), one side of the bicentennial quilt features an embroidered depiction of the Solar System. The other side is made in the tradition of patchwork squares stitched together in a grid, with images of an astronomical or geophysical nature.

The RAS Bicentennial Quilt Project launched in October 2019. Volunteers from a variety of backgrounds – scientists, professional sewers, novice crafters, RAS staff and Fellows – gathered together to take part in stitching afternoons. Together, they began to embroider the orbital paths of the planets. The first few squares for the patchwork side of the quilt began to trickle in. And then the pandemic hit. The RAS offices closed and the stitching sessions were cancelled. Something that relied upon people huddling around a 2m^2 piece of fabric seemed unthinkable. Until, that is, the advent of virtual meetups; the RAS moved its meetings, lectures and events online, so why not the stitching sessions too?

The in-person sewing sessions had proved popular and they did so online too. Despite finding ourselves physically cut-off from one another, these virtual sessions allowed us to connect across the country, across continents and across oceans while we created our own individual squares for the patchwork side. Like the RAS itself, the bicentennial quilt went from a small idea conceived by a few individuals to an international project. We chatted and sewed, shared ideas and advice, provided encouragement and inspiration. A little community was born.

Twelve online stitching sessions took place between April and November 2020 and a total of 100 squares were sent in from all over the globe. Most excitingly, all of the 20cm x 20cm squares we received will be included in the final quilt. They are miniature masterpieces in their own right, together forming a patchwork of nebulae, comets and planets, and also a collective understanding and appreciation for astronomy and geophysics. The quilt is a rich tapestry of experiences and stories that belong to the makers behind each square. What started as a tribute to the RAS's bicentenary has also become a celebration of people's enthusiasm, creativity, skill and resilience.

We've started the process of sewing the squares together, but there's still a lot of work to be done before the quilt is completed, particularly on the Solar System side. For more updates about the project visit **www.ras.ac.uk** and search 'quilt'.

ANNIE HOGAN/RAS BICENTENNIAL QUILT PROJECT

BBC

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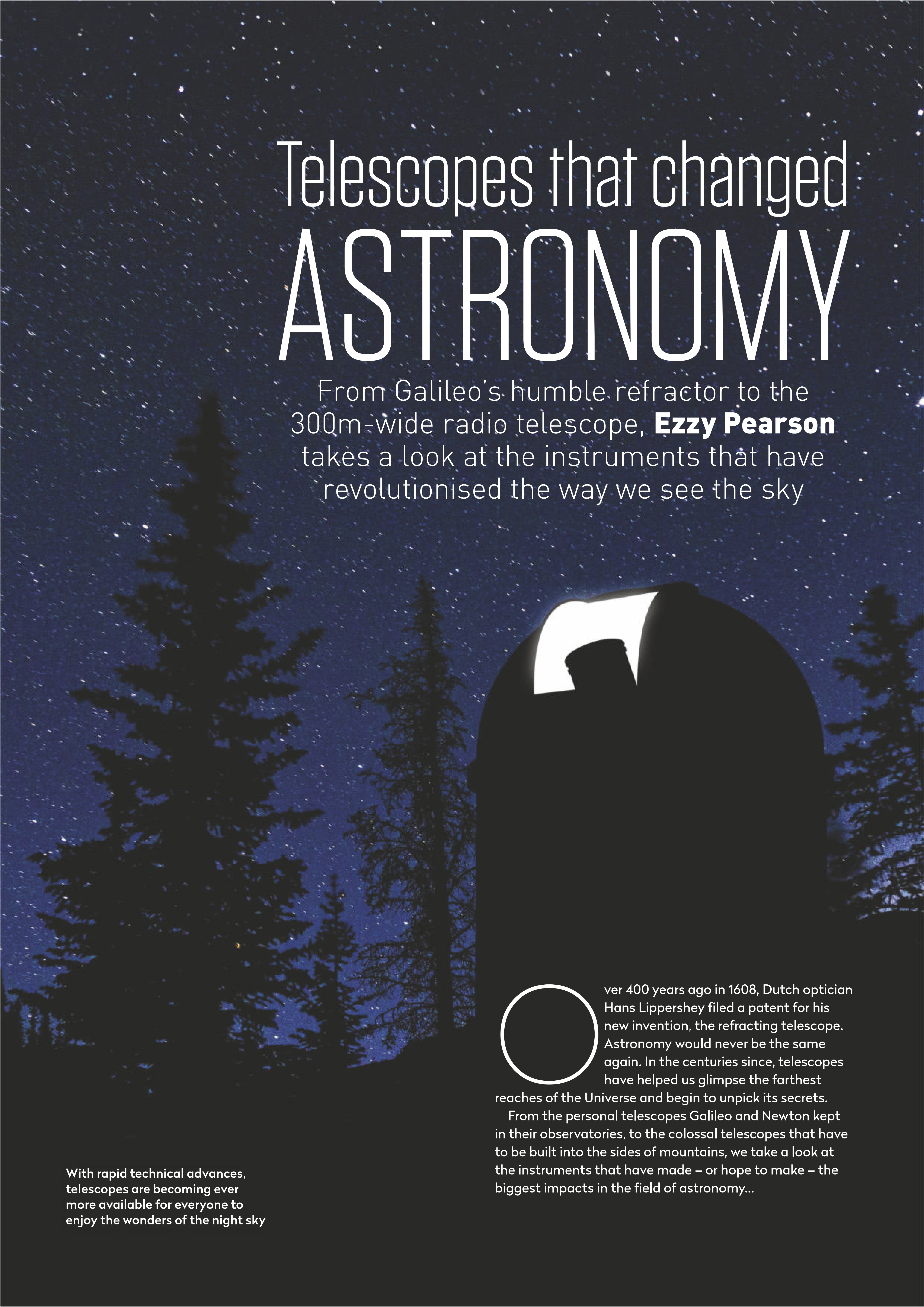
Telescopes that changed ASTRONOMY

From Galileo's humble refractor to the 300m-wide radio telescope, **Ezzy Pearson** takes a look at the instruments that have revolutionised the way we see the sky



With rapid technical advances, telescopes are becoming ever more available for everyone to enjoy the wonders of the night sky

Over 400 years ago in 1608, Dutch optician Hans Lippershey filed a patent for his new invention, the refracting telescope. Astronomy would never be the same again. In the centuries since, telescopes have helped us glimpse the farthest reaches of the Universe and begin to unpick its secrets.

From the personal telescopes Galileo and Newton kept in their observatories, to the colossal telescopes that have to be built into the sides of mountains, we take a look at the instruments that have made – or hope to make – the biggest impacts in the field of astronomy...

GALILEO'S TELESCOPE ▷

The Italian astronomer was the first to systematically map the heavens

In May 1609, Galileo Galilei learned of a remarkable new invention from the Netherlands that used lenses to make distant objects look as if they were nearby. Such a device could finally bring the heavens he studied into view, so he set about creating his own versions and increased the magnification up to 20x.

One of Galileo's first targets was the Moon and his telescope revealed the craters and mountains on its grey surface. He also observed the next brightest object in the night sky: Jupiter. On 7 January 1610, he noticed it was joined by "three fixed stars, totally invisible by their smallness" that seemed to align perfectly with the planet. Over the next few nights he found they weren't fixed at all, but moved with Jupiter. On 13 January he noticed a fourth. These weren't stars, but moons orbiting the planet.

By March, Galileo had published his findings in his seminal book, *Sidereus Nuncius*. It provided compelling evidence that Copernicus was right in his theory that the Sun, not Earth, was at the centre of the Universe, and that the telescope would be the most powerful tool yet for exploring the cosmos.

Two of Galileo's early 'optik tubes' with tiny lenses: they were about 1.5 inches across

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◁ NEWTON'S TELESCOPE

The design that formed the foundation of every modern reflector

► A replica of Newton's telescope. His spherical primary mirror tackled the issue of chromatic aberration

By the mid-17th century, a common lament was heard among astronomers: why were there coloured bands at the edge of their telescope's view? It was Sir Isaac Newton who realised this effect, known as chromatic aberration, was created by the edge of the lens in the telescope acting like a prism and splitting the white light of stars into several colours.

Several telescope makers were attempting to fix the problem by using mirrors, instead of lenses, to focus light. The theory was sound, but was proving difficult to put into practice. Ideally, you'd need a parabolic mirror, but these were hard to produce by hand. Newton used a spherical mirror, which was easier to grind. This solved the chromatic aberration, but introduced another optical defect, spherical aberration, where the image doesn't focus uniformly. Newton also used a secondary mirror so the image could be viewed more easily from the side of the telescope.

Newton showed his telescope at the Royal Society of London in 1671 and it was such a hit that he was asked to demonstrate it to King Charles II. Fifty years later in 1721 another astronomer, John Hadley, worked out how to create parabolic mirrors, eliminating the spherical aberration. Today the Newtonian design is the foundation of almost every reflecting telescope available on the market. ►

ADVENTURE_PHOTO/ISTOCK/GETTY IMAGES, GIANNI TORTOLI/SCIENCE PHOTO LIBRARY, WORLD HISTORY ARCHIVE/ALAMY STOCK PHOTO

HUBBLE
SPACE TELESCOPE

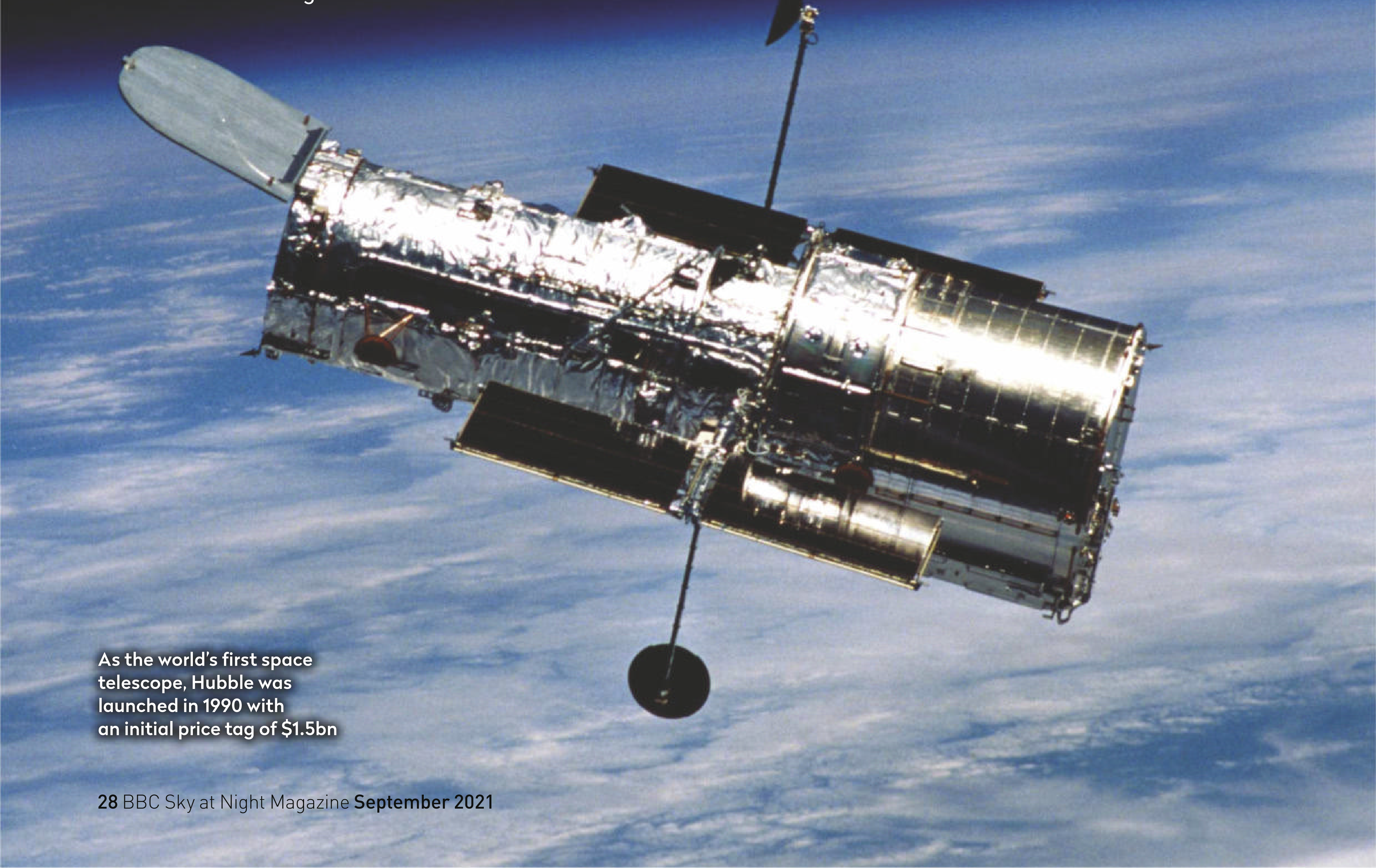
Above the atmosphere, Hubble could get an uninterrupted view of the cosmos

Astronomers have long dreamed of putting a telescope in space. Above the clouds and able to point away from the Sun, such a telescope could observe 24 hours a day without atmospheric disturbance or light pollution. But it would take until 1990 – and the work of both NASA and the European Space Agency (ESA) – to make the dream a reality. On 24 April that year, the first ever visual space telescope, Hubble, launched into orbit.

But the joy of launch was short-lived when it became apparent that the 2.4m-wide mirror was too flat. The error was around 1/50th the thickness of a human hair, but it stopped the mirror focusing properly and its images were blurred. Fortunately, Hubble was made to be upgraded. In December 1993, a service mission installed a new instrument to fix the problem, bringing the Universe sharply into focus.

Over the last 30 years, Hubble has revolutionised our view of the cosmos, imaging everything from neighbouring planets to distant galaxies. Its data has been used in over 15,000 science papers while its images have become part of popular culture. Recently, it was feared that Hubble's days might soon be over. In June 2021, a computer fault shut down the telescope, but operators have re-established contact and fixed the problem. It now looks like the reign of Hubble is set to continue.

One of Hubble's most iconic images has been captured twice: this is the 25th anniversary image of the 'Pillars of Creation', taken in 2014



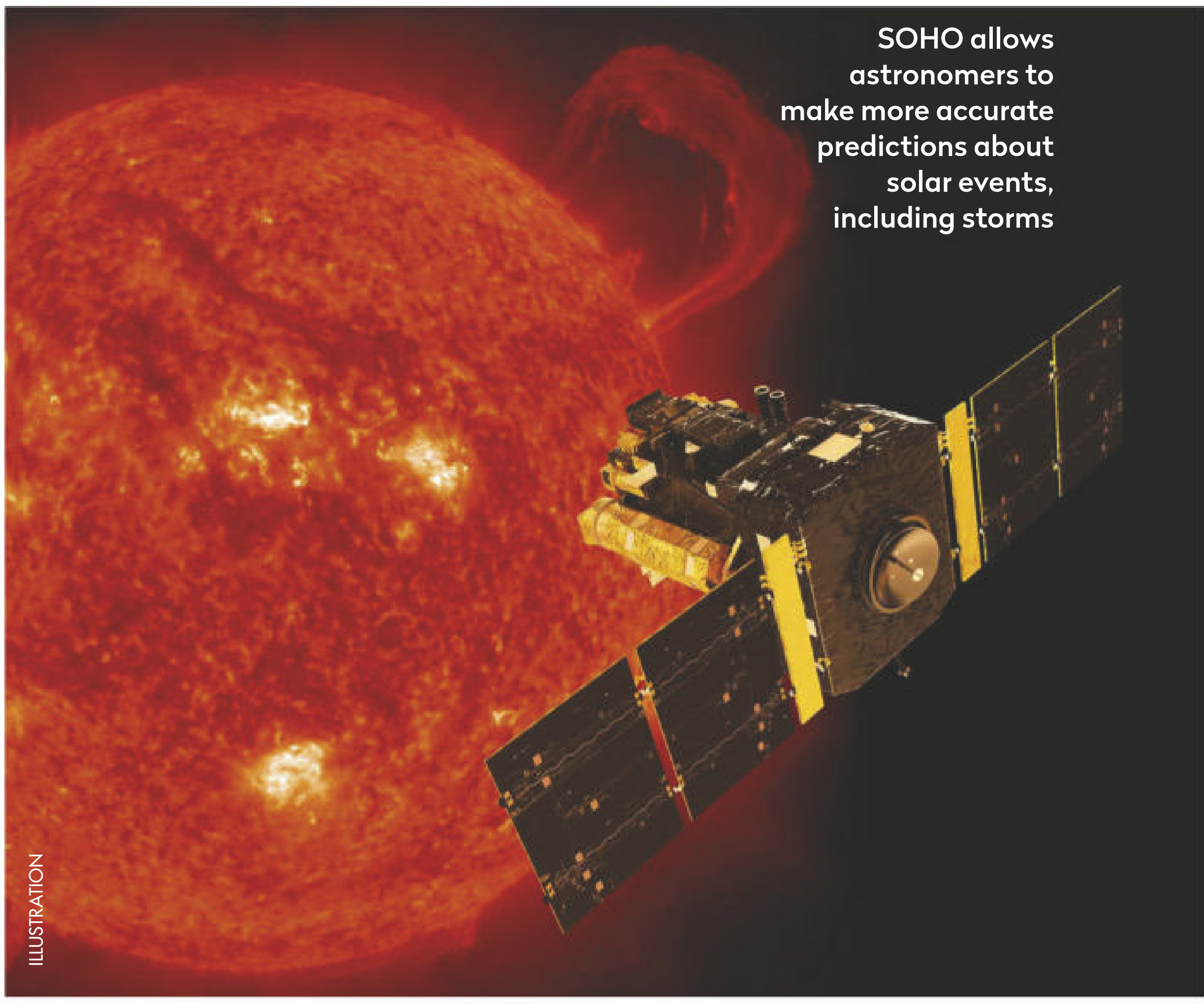
As the world's first space telescope, Hubble was launched in 1990 with an initial price tag of $1.5bn

SOHO ▷

For 25 years, the SOHO spacecraft has kept a close watch over the Sun

While most telescopes are pointed away from the Sun, the Solar and Heliospheric Observatory (SOHO) has spent the last 25 years looking at it. The spacecraft, a joint mission of ESA and NASA, was meant to study the Sun for just two years, investigating its expansive outer atmosphere, surface and internal structure. This meant astronomers could predict solar storms, which can harm astronauts and damage space hardware, a week earlier than before. It launched in 1995, but has proved so useful that its mission has been extended multiple times.

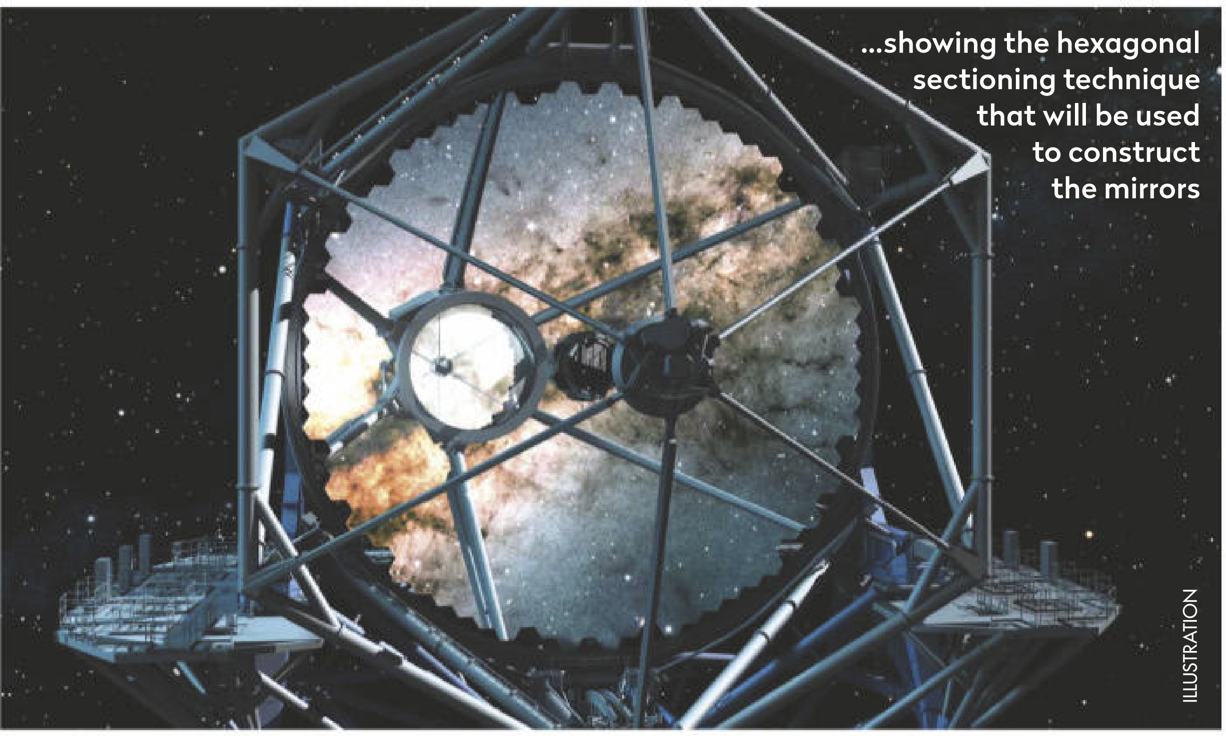
For over two decades, SOHO has provided a near real-time view of the solar surface, allowing astronomers to predict solar storms earlier than they could before. Its watch has extended through two of the Sun's 11 year-long solar cycles, giving insights that enable astronomers to accurately forecast space weather trends over decades rather than days.


SOHO allows astronomers to make more accurate predictions about solar events, including storms

ILLUSTRATION


Artists' impressions of the E-ELT in Chile and (below) the TMT in Hawaii...

ILLUSTRATION


...showing the hexagonal sectioning technique that will be used to construct the mirrors

ILLUSTRATION

◁ EXTREMELY LARGE TELESCOPES

Technological advances enable the construction of truly enormous scopes

When it comes to astronomical telescopes, bigger is better. A larger dish gathers more light and increases the resolution, making detail sharper. For telescopes on Earth, however, once mirrors get beyond a few metres wide, atmospheric seeing – where the shifting atmosphere distorts incoming light – blurs the image. This makes building anything larger pointless.

Until 1990, that is, when the European Southern Observatory (ESO) pioneered a new technology called adaptive optics, which subtly deforms the shape of the mirror to correct for the effects of seeing. Now the only limitation was how big you could make your mirror, leading to a new generation of telescopes dubbed Extremely Large Telescopes (ELTs) that will look deeper and with more precision than anything that has gone before.

There are two ELTs currently in construction. The Thirty Meter Telescope (TMT) will have a 30m-wide mirror and is being built on Hawaii's Mauna Kea, with an expected first light in 2027. Elsewhere, the 39.3m-wide European Extremely Large Telescope (E-ELT) is being built in Chile, ready to start observing in 2025.

Building such large mirrors is a challenge: both mirrors are being split up into dozens of hexagonal sections that will be placed together in a honeycomb to create one giant mirror surface. ▸

NASA/ESA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA), NASA, ESA/ATG MEDIALAB/ESA/NASA SOHO, ESO, TMT INTERNATIONAL OBSERVATORY

ARECIBO TELESCOPE ▷

The huge radio dish opened up the radio Universe

In 1974, the Arecibo Telescope was used to send an interstellar radio message to see if aliens might respond

Built into a sinkhole in Puerto Rico, the 305m-wide Arecibo telescope reigned as the largest radio telescope in the world for over half a century. And yet when it was first put to use in 1963, its primary purpose wasn't scientific, but military – detecting missiles bound for the US. In 1967 however, it was transferred to the National Science Foundation, becoming a scientific facility.

The first change made was the installation of S-Band radar equipment, which could observe Solar System objects as far out as Saturn. This was used to create radar maps of Mars ahead of the Viking lander missions, as well as glimpsing beneath the clouds of Venus and finding ice on Mercury.

Looking further afield, Arecibo has detected the faint signals from distant radio sources and was key in studying pulsars. In 2007 it detected the first repeating fast radio burst, proving that they aren't caused by one-off cataclysmic events, such as stellar collisions.

The telescope lasted 57 years, but in August and November 2020, two of its support cables snapped, damaging the dish. It was due to be decommissioned, but on 1 December a third-cable breakage caused a support tower to collapse, completely destroying the telescope.

JAMES WEBB SPACE TELESCOPE ▽

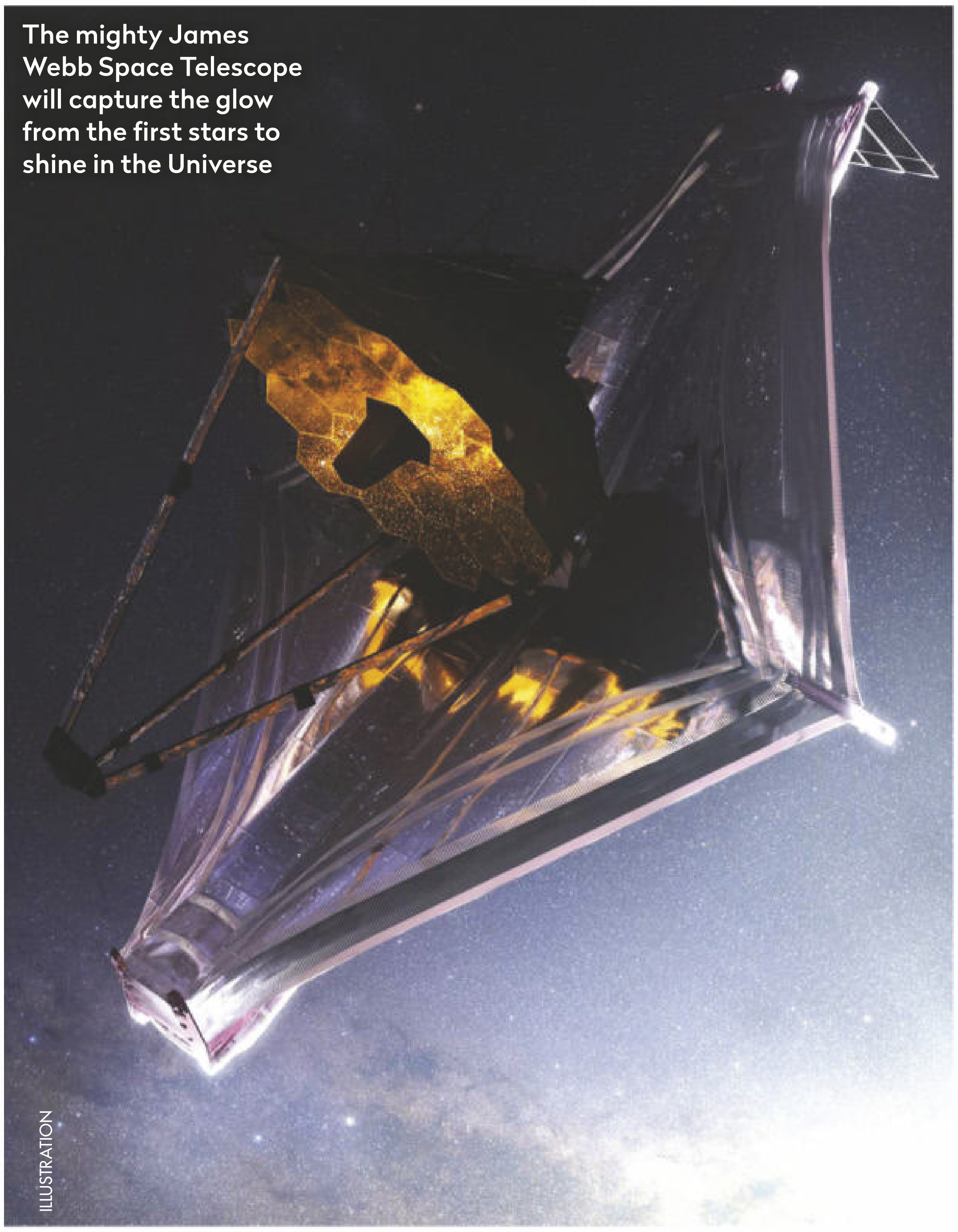
Peering through cosmic dust, JWST will expose how stars and galaxies grow

In 1996, Hubble's glorious images had been making headlines for several years and NASA, keen to follow up on its success, began working on what's now known as the James Webb Space Telescope (JWST).

The JWST's main science goals are to look at how galaxies, stars and planets have grown from the earliest eras of the Universe to today. To do this, it will look at infrared radiation, which can pass through the dust in space that obscures visible light, allowing it to peer into the stellar nurseries and the cores of active galaxies. The radiation also allows it to see objects, such as planets, which are too cool to glow in the visible spectrum.

However, as the telescope's own heat will produce infrared energy, JWST is being kept shaded from the Sun's heat with a huge sunshield. This has proved to be the telescope's most troublesome component. The shield is made of five layers of delicate foil, each the size of a tennis court, one of which tore in 2018 causing the entire mission launch to be pushed back.

After 25 years of planning, building and delays, the JWST is finally ready to launch. Earlier this year both the sunshield and the 6.5m mirror were folded up so that they could fit on board an Arianne 5 launch rocket, ready – hopefully – to head to orbit in November this year.



The mighty James Webb Space Telescope will capture the glow from the first stars to shine in the Universe

ILLUSTRATION

Dr Ezzy Pearson is *BBC Sky at Night Magazine*'s news editor. She has a PhD in extragalactic astronomy

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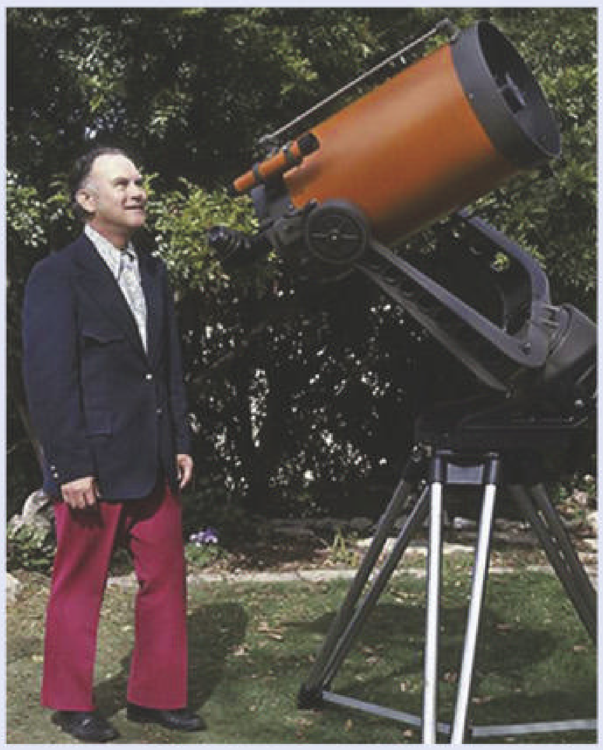
Stargazing for everyone

In the 1960s and '70s, two new types of telescope helped to bring the heavens to more people than ever before

▲ A vintage Celestron C8 from the 1970s with its trademark orange tube...



▲ ...and Celestron founder Tom Johnson with a 14-inch version of his SCT line

In the early days of astronomy, any budding stargazer had one huge hurdle to overcome: getting a telescope. For centuries, the only way to acquire one was to either buy an expensive, hand-made model from a master telescope maker, or spend hours laboriously grinding lenses or mirrors to make your own. It was the latter approach Tom Johnson took when he introduced his sons to stargazing in America in the late 1950s.

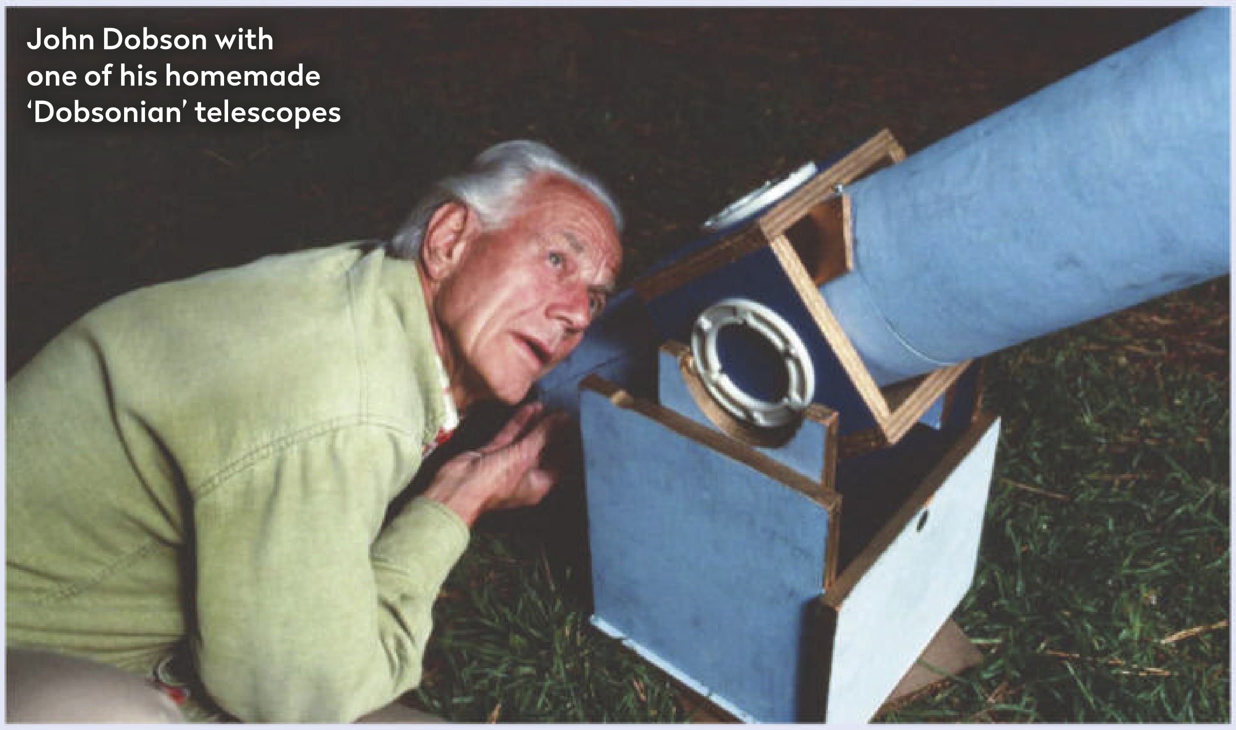
As he worked on the project, Johnson became more and more convinced there was an easier way to make telescopes. Just like Sir Isaac Newton, he was using easy-to-craft spherical mirrors, but using a Schmidt corrector plate to remove the spherical aberrations. Invented by Bernhard Schmidt in 1930, this was a glass plate positioned across the opening of the telescope tube, adjusting the incoming light so that it focused properly, even on a spherical mirror. Johnson found a way to mass-produce these plates. By the early 1960s he had his own telescope company, Celestron (part of Valor Electronics), and began creating high-quality, yet affordable, telescopes for the mass market.

In 1970, Celestron created what would become its flagship telescope, the C8. The 8-inch telescope hit a sweet spot – it was large enough to view deep-sky objects, but not so big as to be unwieldy and expensive. With its distinctive orange barrel it was a huge success.

Yet the C8 still came with a fairly hefty $1,000 price tag (approximately $7,000, or £5,050, in today's money) that was beyond the range of many would-be astronomers.

Thankfully for the more budget-conscious, another astronomer, John Dobson, had been working on making it easier to build your own telescope. His design reduced the instrument down to its most basic elements – the optics, a truss to hold them and a simple swing mount like those used on cannons for centuries. Dobson used affordable porthole glass along with other cheap materials to create large amateur telescopes, which, while not offering as high-quality views as commercially built telescopes, cost a fraction of the price. He encouraged people around the world to copy his design and today 'Dobsonian' telescopes are a common sight at any star party.

The C8 and the Dobsonian helped to bring the stars within reach of the masses.



John Dobson with one of his homemade 'Dobsonian' telescopes

▲ Celestron's most advanced 8-inch system is currently the CGEM II 800 EdgeHD (right); while Dobsonian telescopes have also come of age with computerised models like the Skyliner-200P Flextube SYNSCAN Go-To (left)

The fundamentals of astronomy for beginners

EXPLAINER EXTRA

Here comes the dark-sky season!

With darker skies upon us, **Scott Levine** takes a month-by-month tour of the must-see sights for the longer nights around the corner

The start of autumn in the Northern Hemisphere is just a matter of weeks away, but we can already see the nights getting longer, with sunsets now over an hour and a half earlier than they were around the June solstice. As these earlier nights for observing come along, let's look at the exciting sights we can look forward to seeing as the dark-sky season begins.

September

With September here, the long summery days are gradually changing into early nights. Indeed, we'll see spring and summer's stars making way for the dark-sky season as autumn approaches.

Let's begin our dark-sky adventure at a well-known asterism, the **Plough**, sitting upright just above the northern horizon. The next bright star to its south-southeast is **Arcturus** (Alpha (α) Boötis), which we usually think of as a springtime star.

Next, high overhead, we find the **Summer Triangle**'s stars: **Vega** (Alpha (α) Lyrae), **Altair** (Alpha (α) Aquilae) and **Deneb** (Alpha (α) Cygni), and then drop towards the east for the **Great Square of Pegasus**. Maybe we can spot **Capella** (Alpha (α) Aurigae), just above the northern horizon.

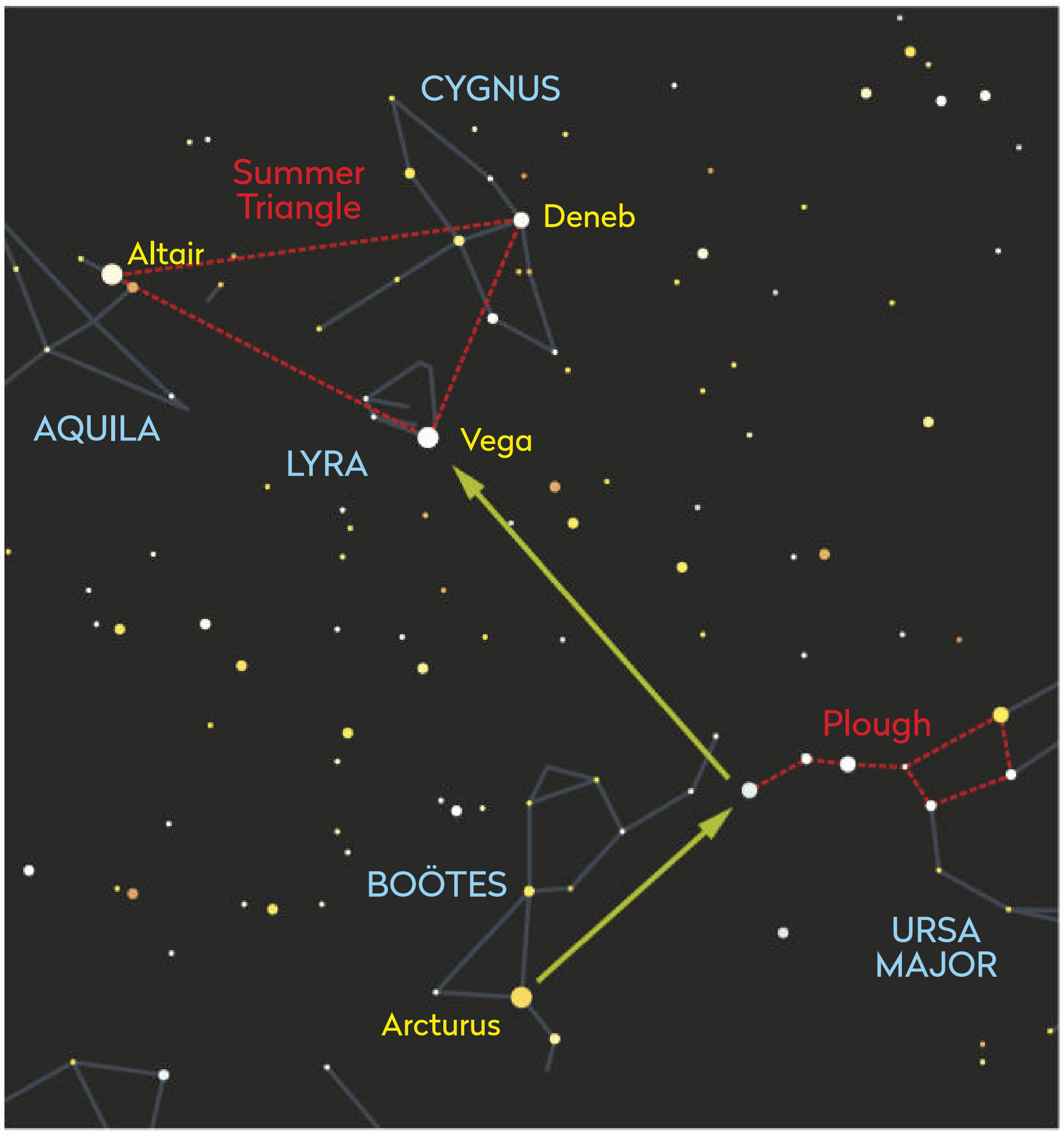
With binoculars, let's look for the **Andromeda Galaxy, M31**, just to the northeast of **Pegasus, the Winged Horse**, and then the **Double Cluster** in **Perseus, the Hero** a bit further northeast.

Meanwhile, the **Moon** catches up with **Jupiter** and **Saturn** on 17 September. With good telescopes, we may be able to see deep, blue **Neptune** to their east. The planet reaches opposition on the 14th.

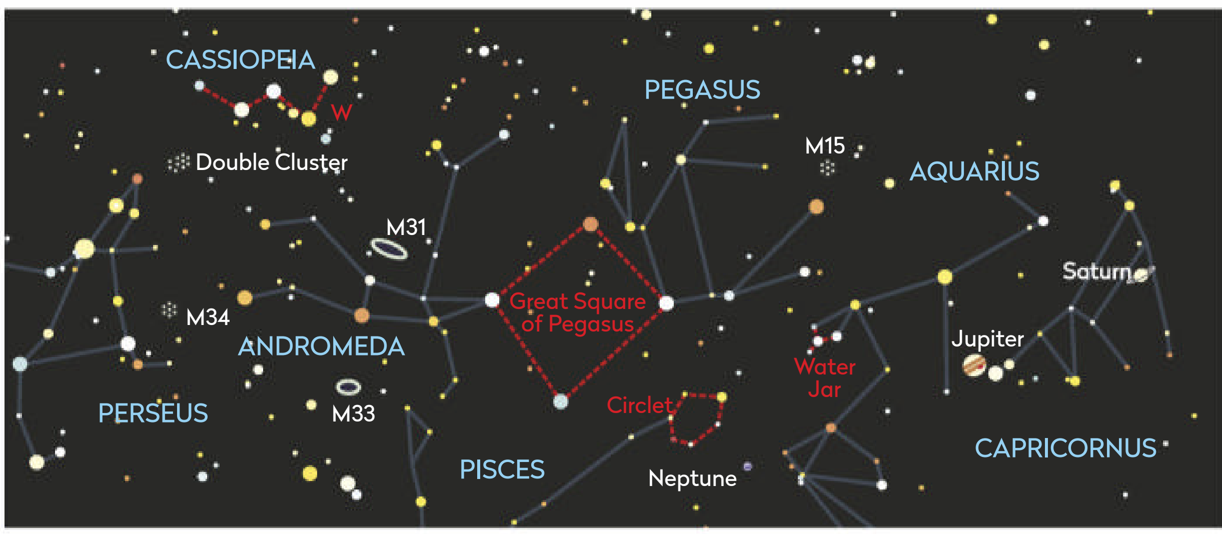
October

With the autumn equinox (22 September) behind us, there's more night than day now for the first time since March, and it'll stay that way until March 2022.

Fomalhaut (Alpha (α) Piscis Austrini) is almost due south at mid-evening. It's the southernmost first-magnitude star we can see in the Northern Hemisphere, in a part of the sky without many

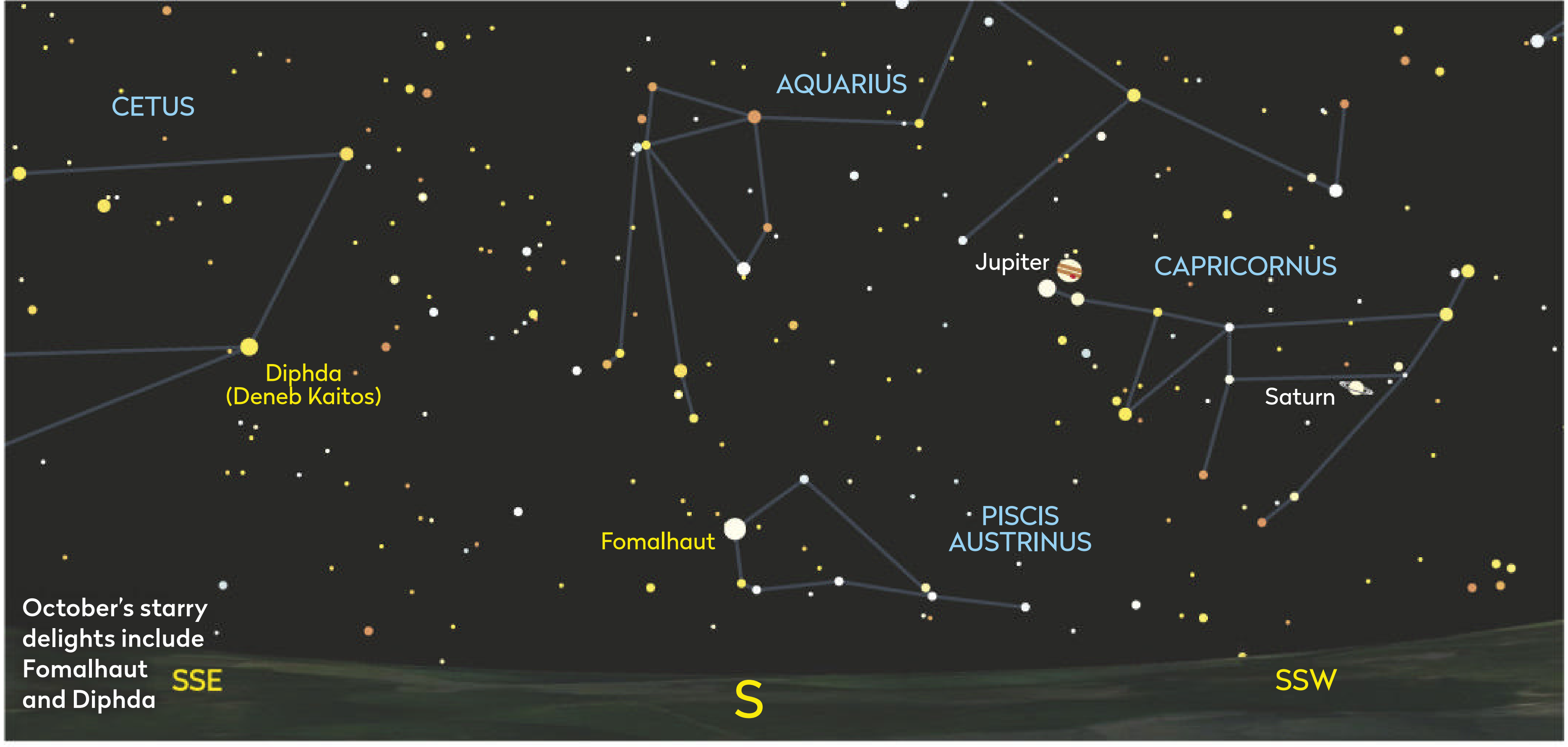


▲ In September, the Plough connects to Arcturus and the Summer Triangle...



▲ ...and we can use the Great Square of Pegasus to find the Andromeda Galaxy, M31

CHARTS: PETE LAWRENCE



other bright stars. With so little happening nearby, it appears as a slightly oddball light a few degrees above the horizon. **Diphda** (Beta (β) Ceti), also known as Deneb Kaitos, is about 25° east of Fomalhaut.

The waxing gibbous **Moon** meets up with **Jupiter** and **Saturn** on the 14th, about 25° to Fomalhaut's west. Through binoculars, we can see the shadows reaching across the Moon's face as lunar dawn breaks along its mid-section.

On the 23rd, the Moon glides between the **Hyades** and the **Pleiades** star clusters, and starts moving across the **Winter Hexagon**. **Venus** reaches greatest elongation, about 46° east of the Sun, on the 29th.

Back in the north, the starry constellation of **Cassiopeia, the Queen** is high overhead with **Cepheus, the King** to its west, **Perseus, the Hero** to its east and the **Milky Way** running through them all.

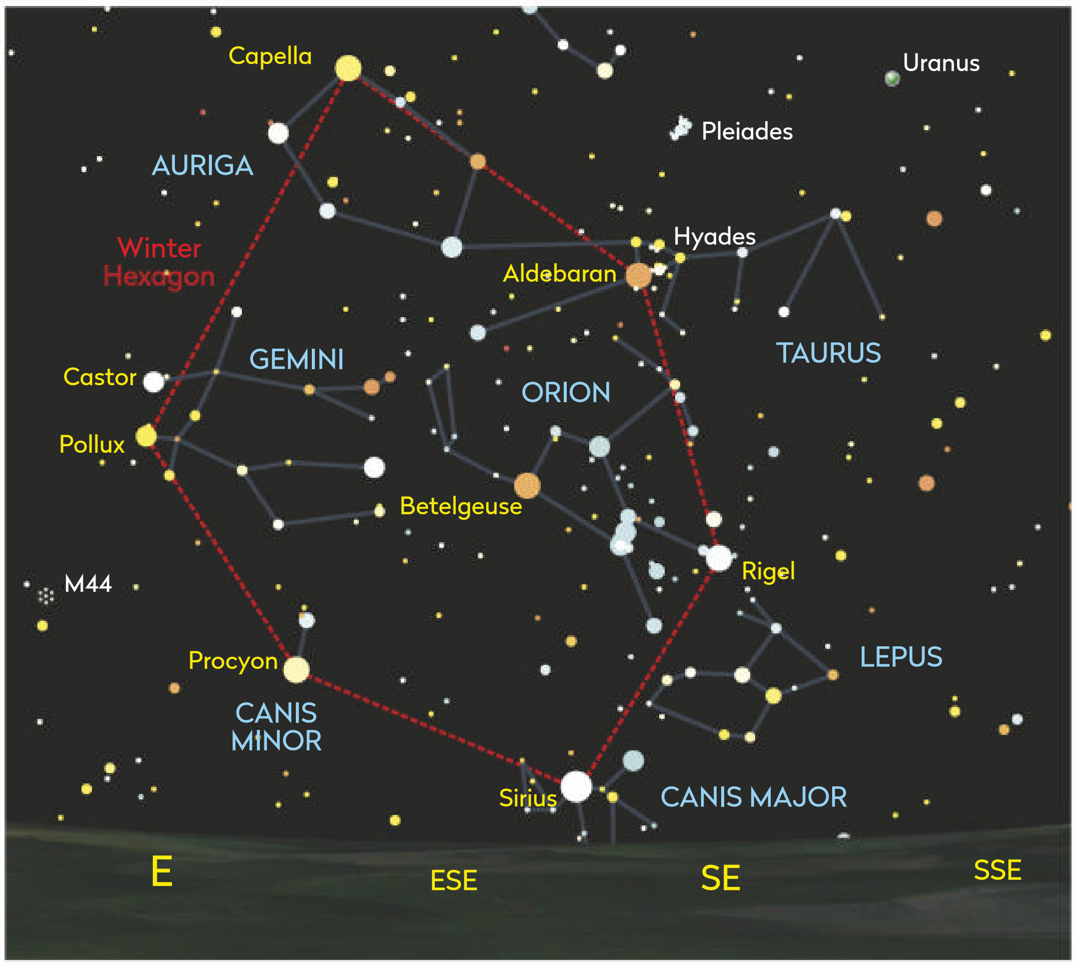
November

Deeper into autumn, the Plough is low above the northern horizon. Arcturus has departed now, but let's follow the line between **Megrez** (Delta (δ) Ursae Majoris) and **Dubhe** (Alpha (α) Ursae Majoris), across the top of the blade to **Capella**, whose golden colour is stunning on these stark nights.

Widening our gaze, we can see most of the **Winter Hexagon**: the asterism of six of the sky's brightest stars, one each in six constellations, covering a patch of sky so enormous that the Moon needs four nights to cross it. Anti-clockwise around it are **Capella**, then **Pollux** (Beta (β) Geminorum), **Procyon** (Alpha (α) Canis Minoris), **Sirius** (Alpha (α) Canis Majoris), **Rigel** (Beta (β) Orionis), and **Aldebaran** (Alpha (α) Tauri).

Aldebaran marks the southeast end of the southern arm of the V-shaped **Hyades**, with the tiny, dipper-shaped **Pleiades** a short hop away. They're among the closest star clusters to us, about 150 and 450 lightyears away respectively. They're truly stunning in binoculars and worth observing for a good, long time. Aldebaran isn't part of the cluster, but it sits about halfway between the Hyades and Earth. The (almost, to first quarter) **Moon** passes through on the 10th and 11th, and the full Moon splits the clusters on the 19th.

When it comes to the planets, we can also catch **Jupiter** and **Saturn** in the early evening, and a pair of binoculars will help you spot **Uranus**, which at mag. +5.7 is on the verge of naked-eye visibility, when it's at opposition on the 4th.



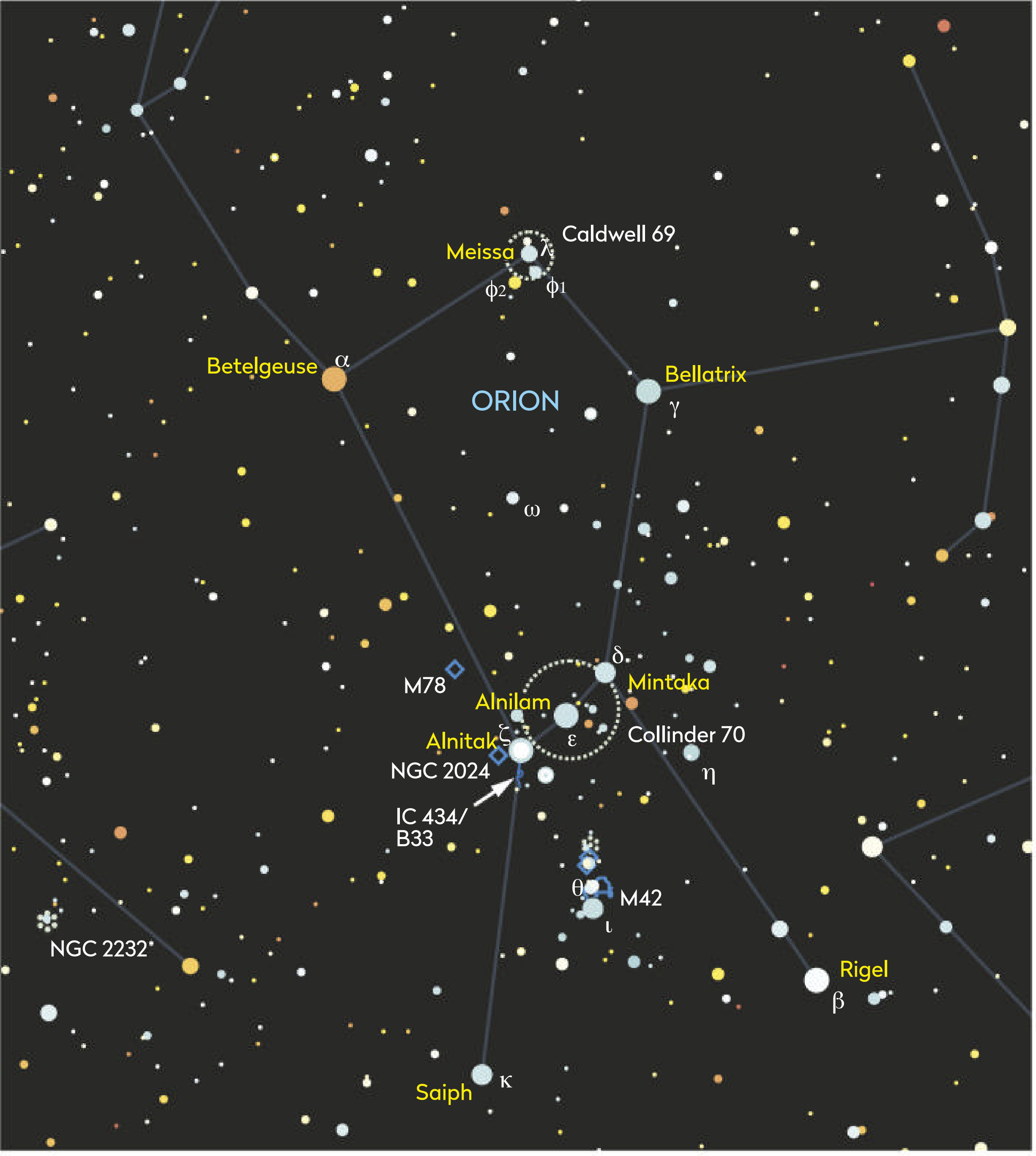
▲ November offers the perfect opportunity to explore the stars in the Winter Hexagon, including Aldebaran, a useful marker for the Hyades and the Pleiades star clusters

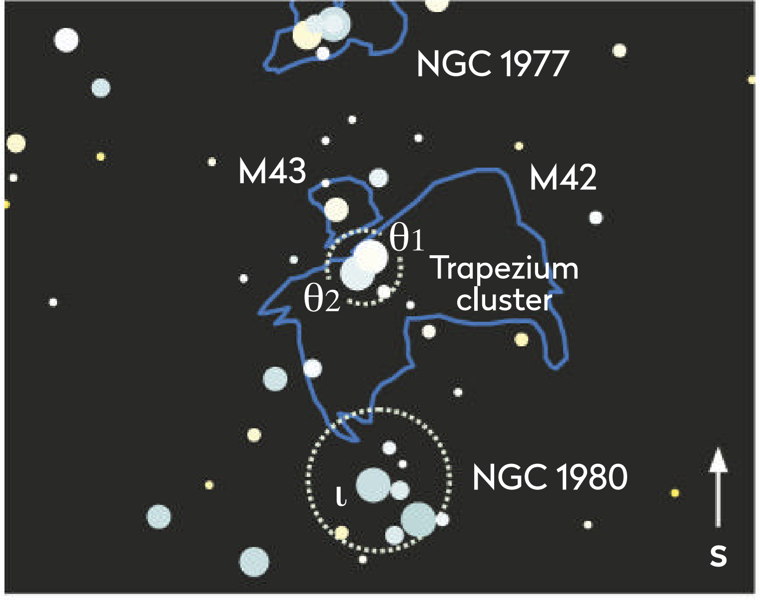
December

The start of winter is just three weeks away now, at the winter solstice on the 21st, so these are the year's longest nights. With sunset before 16:00 UT these are my favourite nights for observing in the year. Indeed, let's spend a little extra time simply soaking in that extra darkness without any worry about which star is which.

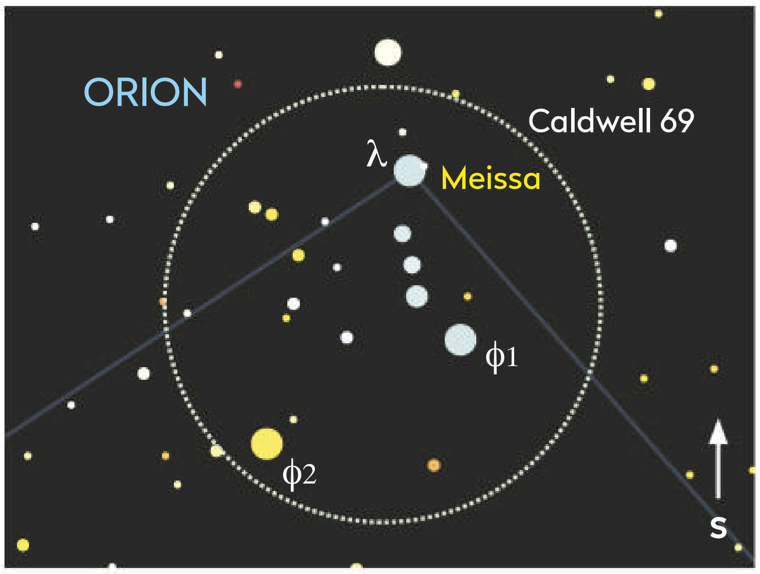
This is also the start of **Orion** season! All of the Hunter's seven famous stars are above the southern horizon by mid-evening, but can you remember their names? The red supergiant **Betelgeuse** (Alpha (α) Orionis), and **Bellatrix** (Gamma (γ) Orionis) are his shoulders. **Saiph** (Kappa (κ) Orionis), and icy blue **Rigel** are his feet. The belt stars are **Alnitak** (Zeta (ζ) Orionis), **Alnilam** (Epsilon (ε) Orionis), and **Mintaka** (Delta (δ) Orionis). Let's visit them as they rise a little earlier each night and make their way a little further to the west at the same time each night.

Many of us also know the **Orion Nebula**; the star- ▸





▲ A small telescope will show you the Trapezium Cluster in the middle of Orion's Sword...



▲ ... and you'll see a ladder of three stars extending from the star Meissa within Orion's head

▸ forming region in the middle of his sword, with the **Trapezium Cluster** deep within it. Let's look at his head too; **Meissa** (Lambda (λ) Orionis) is the brightest star in the **Caldwell 69** open cluster. With binoculars, we can see a dusty glow there, as well as a beautiful ladder of three stars extending from Meissa. **Orion's Belt** is also part of a glowing cluster, **Collinder 70**, with the **Horsehead** and **Flame Nebulae** nearby (Barnard 33 and NGC 2024). The first of these targets is a challenge, needing a large scope and dark skies.

Meanwhile, the **Moon** is a waxing crescent when it joins the gas giants on 8 December, and it's full when it arcs above Betelgeuse on the 19th.

January

Happy New Year! Having passed the winter solstice on 21 December, the nights are slowly shortening.

We're six months from summer now. If you can believe it, the **Summer Triangle** is still with us. It's spent that time crossing high overhead, and now its stars call to us through the wintry western dusk.

The constellation of **Auriga, the Charioteer** is high towards the south in January. Its brightest star **Capella** has the nickname 'The Goat Star', so let's look for the pair of stars called **The Kids**, about 5° to its south. About 10° west of Capella, we'll find **Menkalinan** (Beta (β) Aurigae), with another, almost-matching pair, which I call '**The Cousins**', about 5° to its south. The balance and symmetry of these is something I look forward to all winter.

With binoculars, we can scan the distant star clusters scattered through the constellation, including the **Pinwheel, Salt and Pepper** and **Starfish Clusters (M36, M37** and **M38)**. Let's also see if we can spot some small star chains sprinkled among them.

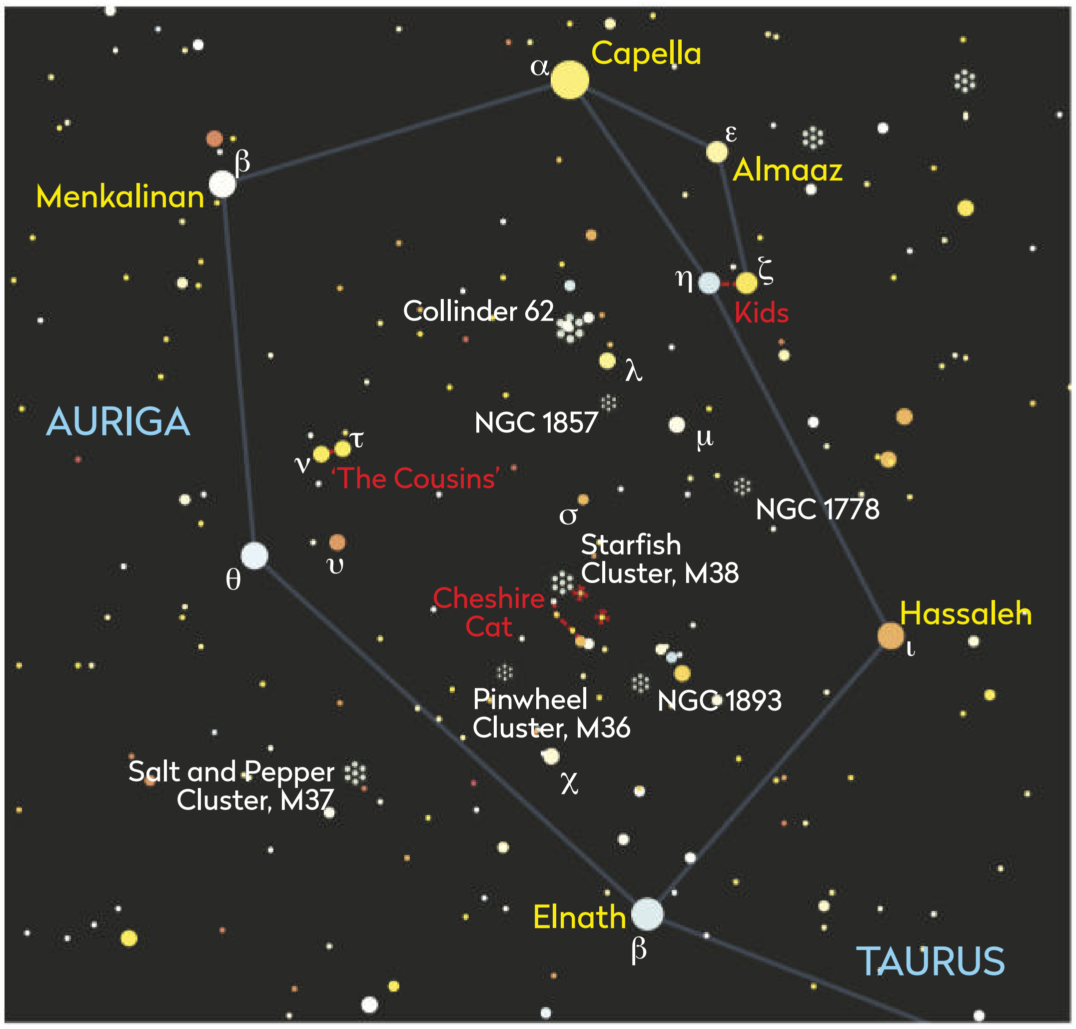
CHARTS: PETE LAWRENCE

▲ December is the time to get to know the sights in Orion, the Hunter

▼ See in the New Year with Capella and enjoy the treasures of Auriga, including clusters M36, M37 and M38

Mirfak (Alpha (α) Persei) and the **Alpha Persei Cluster**, about 20° to the west of Capella, are also an amazing sight through binoculars.

The year 2022 starts with **Jupiter** and **Saturn** lingering in the last of the glowing twilight, with the **crescent Moon** racing through on 5 January. We might also be able to catch **Mercury** alongside Saturn for a couple of nights centred on the 10th, and **Venus** is hiding there too. This could all be tough to see, however, so be patient.



Dark-sky season challenges

Expand on your observing targets each month, whether it's with meteor showers (naked eye), deep-sky objects (binoculars) or planets (telescopes). Here are some suggestions:

SEPTEMBER Try and spot Neptune with a telescope when it's at opposition –in the opposite position on the sky to the Sun – on 14 September.

OCTOBER The peak of the Orionid meteor shower takes place on the night of the 21/22 October. With the Moon out of the way and an expected ZHR (zenithal hourly rate) of 20, it should be favourable for naked-eye observing.

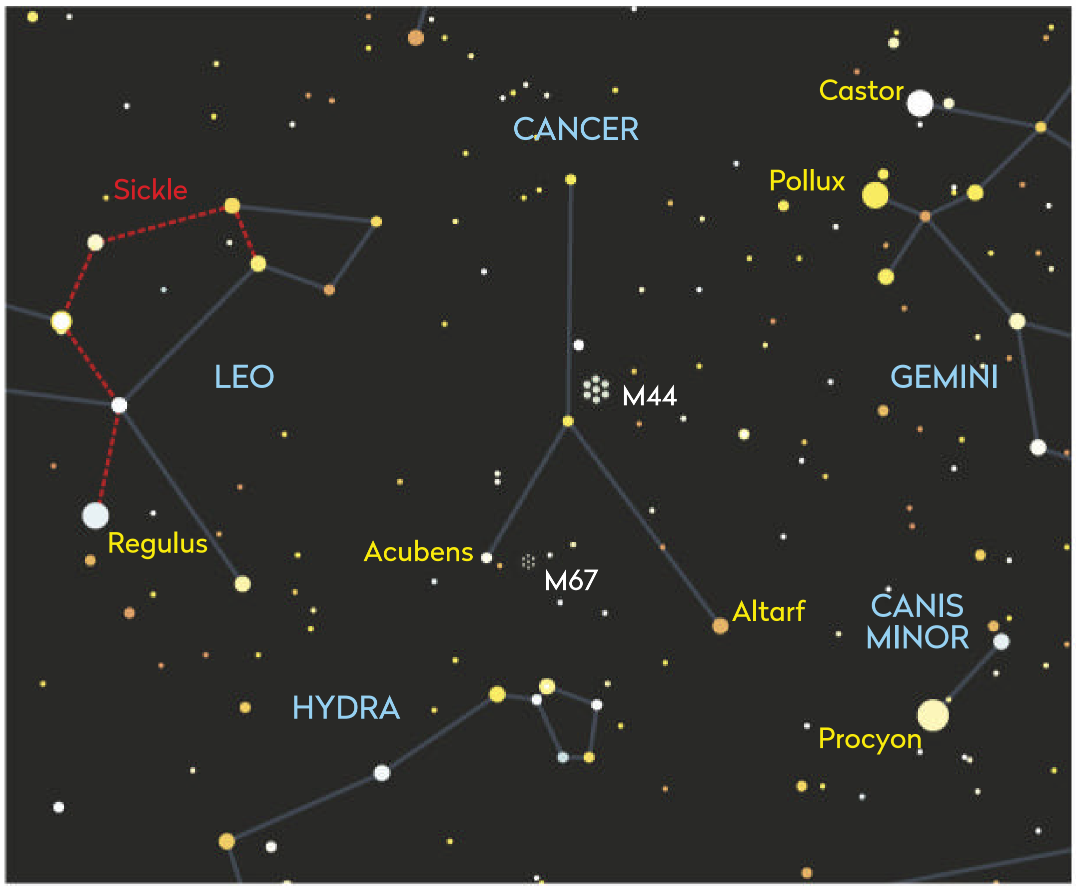
NOVEMBER With binoculars look for the Hyades open cluster in Taurus, the Bull, Also this month, Uranus is at opposition on the 4th.

DECEMBER The Geminid meteor shower peak takes place on 13/14 December with a ZHR of 120.

JANUARY Use binoculars to search for the open clusters M36, M37 and M38 in the constellation of Auriga, the Charioteer.

FEBRUARY This is a good time for getting wide-field views of the Beehive Cluster in the constellation of Cancer, the Crab.

A meteor shower peak, like the Geminids (on 13/14 December) is a wonderful opportunity for astrophotography



▲ In February try and spot the densely populated Beehive Cluster, M44, within the dim constellation of Cancer, the Crab

February

We've come to the last full month of the dark-sky season. The Sun sets an hour later at the start of the month than it did at December's solstice, and we'll see another additional hour of daylight by the end of the month.

All of **Canis Major, the Great Dog** is above the southern horizon by mid-evening now. The 'Dog Star', **Sirius** (Alpha (α) Canis Majoris), culminates – appears at its highest position, due south – at 21:00 UT by mid-month. Around this time we'll notice that **Arcturus** has sneaked back into the night. Its welcoming red glow is a sign that even though we feel the nights shrinking, spring is on its way.

Betelgeuse culminates at 21:00 UT early in the month. With **Orion** standing tall above the horizon, it's a great moment to rewind our minds and remember a few months ago. Back then, those stars were just climbing into the eastern sky as the last of the leaves fell to our feet. Before long, Orion will fall into the dusk as new buds pop onto the trees.

If we search through the dim constellation of **Cancer, the Crab**, in the patch of sky between **Gemini, the Twins** and **Leo, the Lion's 'Sickle'**, we'll find the **Beehive Cluster**'s thousand stars.

Mornings are the best time for spotting planets this month. **Venus**, as it so often does, will stop us in our tracks, glowing just before sunrise. On 5 February, we might be able to spot it with **Mars** and **Mercury** low above the eastern horizon. The **Moon** slides through the **Winter Hexagon** again from the 9th to the 13th, and then waves at Venus as a waning crescent on the 27th. With that, the spring equinox is only three weeks away on 20 March.

There's more than enough to keep any astronomer busy all the way through the dark-sky season until next spring, so let's get started right away and take a look tonight!

Scott Levine is a naked-eye observer and an astronomy writer based in New York's Hudson Valley

So you want to work in SPACE?

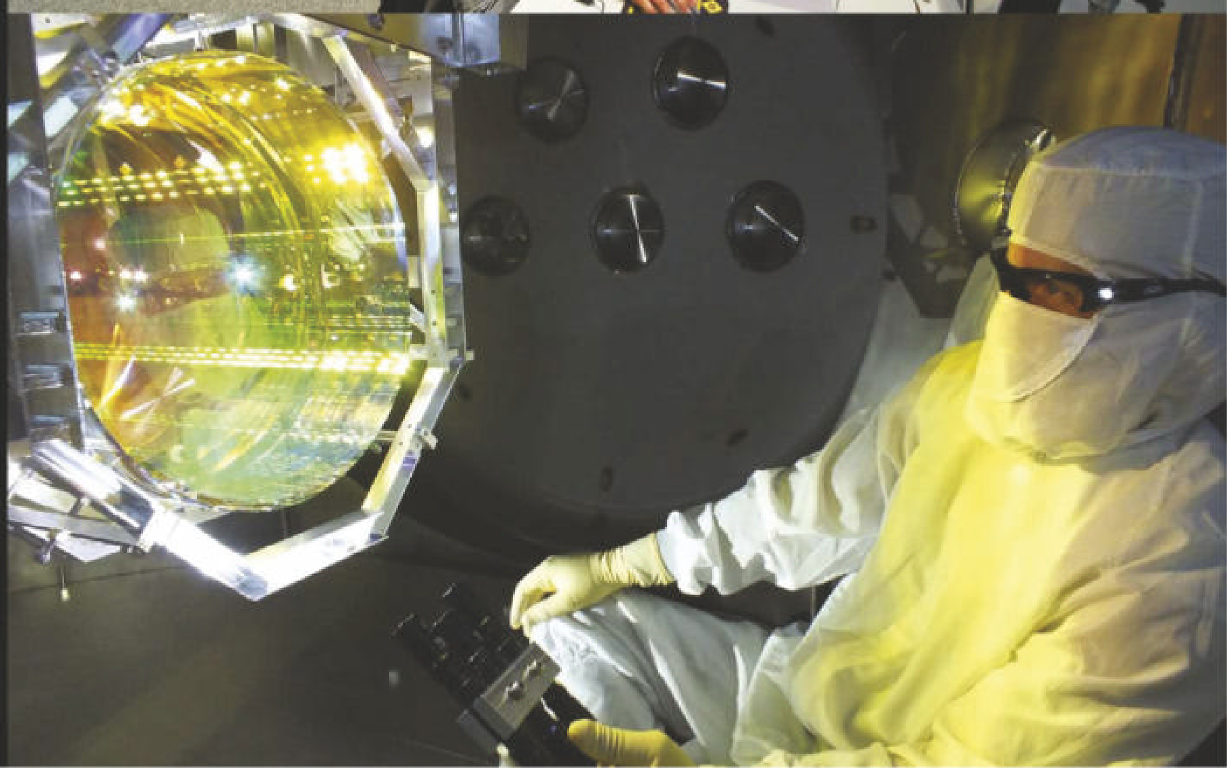
ESA/NASA, BILL INGALLS/NASA/HANDOUT, GCTC, DPA PICTURE ALLIANCE/ALAMY STOCK PHOTO, MATT HEINTZE/CALTECH/MIT/LIGO LAB

The space industry has a wide range of job opportunities, from becoming an astronaut to being a member of Mission Control. You could be part of the team training astronauts to go into space or build devices to search for gravitational waves – the options are almost endless

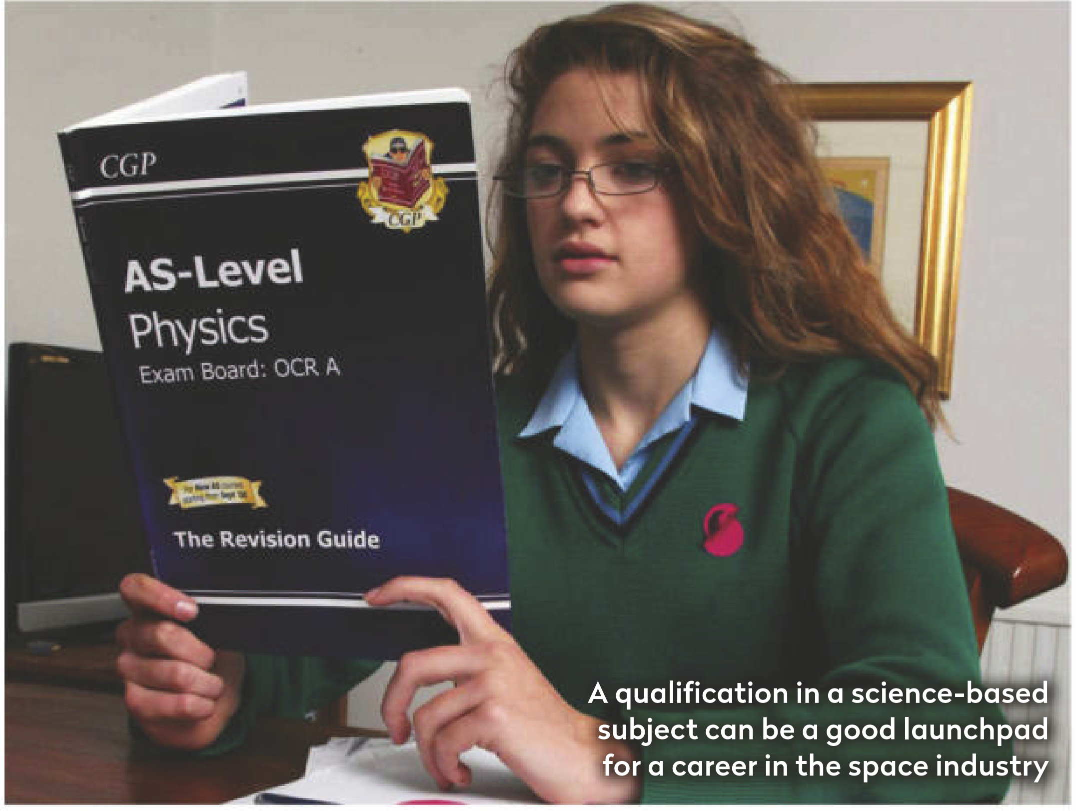
The space sector is thriving. **Hayley Smith** of the National Space Academy reveals how GCSE and A-Level students can prepare for their dream job

Astronauts and astronomers are usually the first jobs that spring to mind when you think of space careers, but have you ever heard of a space lawyer, an astro-ecologist or a space marketing executive? Space offers a wider range of career opportunities than you may think: in engineering, business, web development, writing, accountancy, art, scientific research, data analysis, computing and medicine.

The UK space industry is growing too. It has a total annual income of £16.4bn and employs over 45,000 people. Plus there are seven new spaceports planned to be operational in the UK within the next six years. The UK is also a member of the European Space Agency (ESA), which trains astronauts and launches missions to explore the Solar System and beyond. There are many routes into the space sector, and which one you take depends on your unique blend of skills and interests. ▸



Astronauts in training have entire teams behind them, even underwater!



A qualification in a science-based subject can be a good launchpad for a career in the space industry

Producing illustrations of the cosmos is an opportunity for budding artists to join the space industry

ILLUSTRATION

▲ The National Space Academy holds regular career events for students

► Consider a mission like the James Webb Space Telescope. Engineers design, build and maintain the spacecraft. Computer programmers write code so the spacecraft can perform tasks and communicate with Mission Control. Flight controllers make everything run smoothly. Lawyers ensure legislation is in place for the launch. Astrophysicists analyse data and artists illustrate cosmic phenomena, while writers communicate scientific discoveries to the world.

A mission to the International Space Station (ISS) needs astronauts like Tim Peake to travel into space, maintain the station and perform experiments. A large ground team makes these missions happen, training astronauts, ensuring operations run smoothly and planning the astronauts' schedules. ISS systems are designed, developed and maintained by scientists and engineers. While medics study the effects of microgravity on the human body, doctors and psychologists find ways to overcome the barriers to human spaceflight so we might one day see human footsteps on Mars.

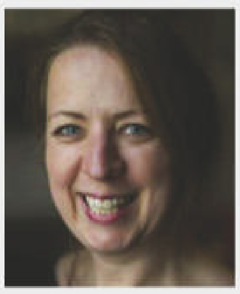
Deciding on a career path

So how do you know which career path you should choose? The good news is that you don't need to decide right away. If you're selecting options for your GCSEs or A-levels, or thinking further ahead to what you might want to do after leaving school, remember that the diversity of careers in the space industry means you don't necessarily need to choose a specific set of subjects.

Think about what you love doing. You're more likely to do well at the things you're passionate about and you'll be happier in your work too. Technical careers, such as engineering, need a good scientific background, so sciences and maths at A-Level will keep your options open. Career events like those run by the National Space Academy are a great way to experience the range of jobs available and meet people from the industry.

Perhaps you already know what job you want to do. Use the job as a starting point and work backwards from it to see what routes will help you get it. Research your chosen career to make sure it's right for you. Often, we only see the most exciting or glamorous parts of a job. Astrophysicists don't spend their time on top of a mountain gazing through a telescope; usually they can be found at a computer

EMPLOYEE PROFILE



Libby Jackson • Job title: Human Exploration Programme Manager, UK Space Agency

Libby looks after the UK's interests in the human spaceflight programme.

"Imagine hopping from one lily pad to another, over a pond. It's a bit misty, but don't lose sight of the other side. Do what you enjoy and don't listen to anyone who tells you that you shouldn't be doing it because of what you look like or who you are or where you're from. If you're enjoying it, do it."

NASA, NASA/ESA/AND G. BACON (STSCI), JOHN BIRDSALL/ALAMY STOCK PHOTO, NATIONAL SPACE ACADEMY, ESA

▲ ESA's *Astronaut Application Handbook* provides great insights into the many roles at the Space Agency and what it takes to get them

in a university, working with data or giving lectures to undergraduates and doing public outreach activities. Astronauts only spend a few weeks or months in space, but undergo years of gruelling training and travelling to get there.

"We aren't looking for supermen and superwomen who are the best at everything, but people who are good at a wide range of activities," says Lucy van der Tas, Head of Talent Acquisition at ESA. "Astronauts need to be physically fit, have good motor coordination and be comfortable with underwater training, which simulates microgravity.

"Our astronauts must be team players and get along with others. That's critical if you're going to spend months in close confinement. They have to stay calm under pressure, so they take the right steps in an emergency. They also need good communication skills and patience, as it can take time to get assigned to that first mission."

An academic route into the space sector might include GCSEs followed by A-Levels, a university degree and possibly a postgraduate qualification, such as a PhD. This is often the route for a career in astrophysics or scientific research. If this sounds like it's for you, explore courses you're interested in, figure out what they entail and what the entry requirements are.

Follow your own route

If your interest lies in astronomy, sciences and maths are important, and most astronomers do a university degree in astrophysics or a related subject.

Sheila Kanani, Education, Outreach and Diversity Officer at the Royal Astronomical Society, did a four-year Master's in Physics and Astrophysics at the University of Manchester, followed by a PhD in Planetary Science at Mullard Space Science Laboratory. This was followed by teacher training and a job as a full-time teacher.

"I was able to go to Australia and also worked with the radio telescope at Jodrell Bank, where I was using pulsar timing data to look for exoplanets around pulsars," she says. "It's been a very winding career path that led me to where I am today. I've got a background in education, but also a research background as well, which I think is really important."

Astronomers use computers for modelling and working with data, so computer programming skills are useful. Join an astronomical society or attend local talks and events, to immerse yourself ▸

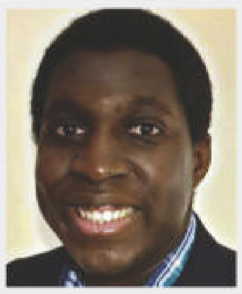
EMPLOYEE PROFILE

Dr Natasha Stephen • Job title: Director of Plymouth Electron Microscopy Centre

Natasha combined her love of geology and space to become a planetary geologist.

"There are lots of opportunities within the space industry, even at an early age. Speaking to people about them is a great way to start. Formal organisations, such as UKSEDS (for students) or the UK Planetary Forum, can help too. Many space engineering companies and science groups offer placements and work experience."

EMPLOYEE PROFILE



Christopher Ogunlesi • Job title: PhD student in Additive Manufacturing, University of Southampton

Chris worked on the BepiColombo mission to Mercury as an ESA young graduate trainee.

"I explore additive manufacturing, which is a fancy way of saying 3D printing. We're printing a thruster for satellites, which allows us to make complex shapes. 3D printing, especially of metal, is a relatively new process so a lot about how that affects materials and their properties isn't really that well understood."

Professor Stephen Fairhurst (below) gives a talk on gravitational waves. He's part of Cardiff University's LIGO group, which helped to detect gravitational waves generated from a collision of two black holes in 2015

ILLUSTRATION

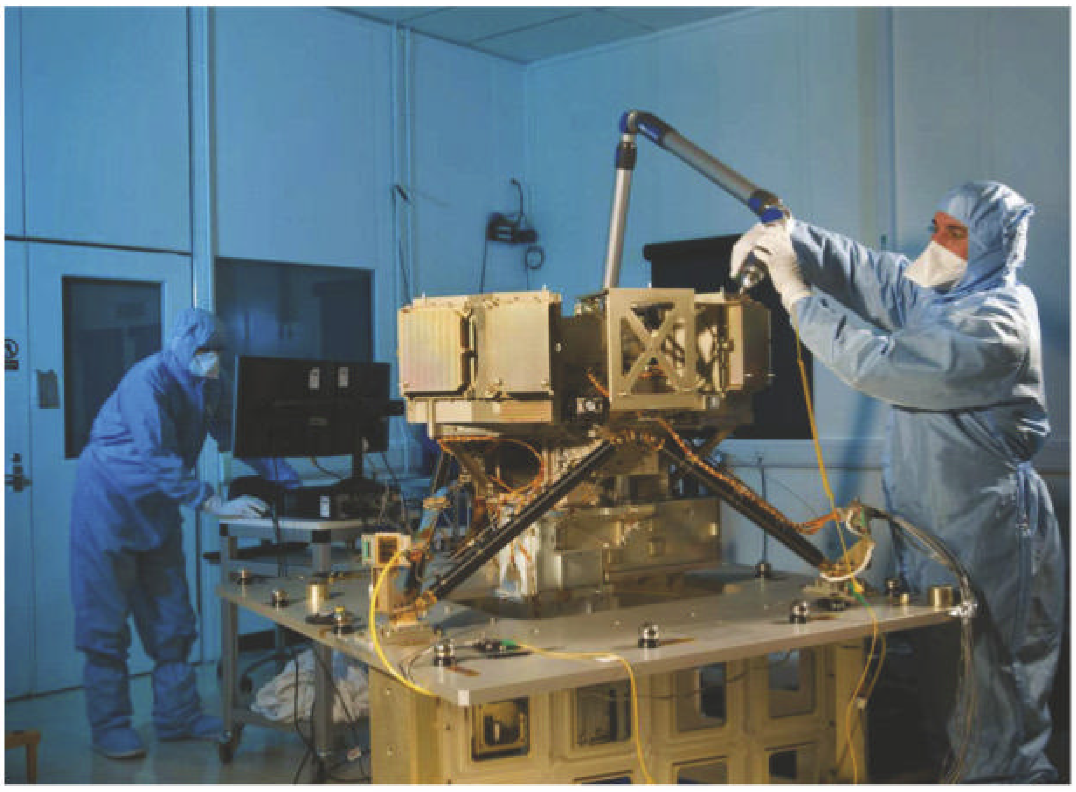
▸ in the subject. As an astronomer you'll conduct research into the processes that govern the Universe and you may end up studying exoplanets, stars, black holes, galaxies or the evolution of the early Universe. Observational astronomers use telescopes and cameras, analysing data to provide a picture of what's happening in the cosmos. Theoretical astronomers use maths and computer modelling to make predictions and explain observations, helping to put pieces of the puzzle in place. To become a professional astronomer, you'll need to study for a PhD in an area of astronomy that interests you. Then you can apply for jobs in universities, observatories or research institutes around the world.

Do some research into the universities that have a good reputation for the particular subject you're interested in. UK universities rated highly for physics and astronomy include the University of Oxford, the University of Cambridge, the University of St Andrews, the University of Manchester and University College London (UCL). Queen's University Belfast has a thriving astrophysics research centre with a teaching observatory for those interested in observational astronomy. Cardiff University is part of the LIGO (Laser Interferometer Gravitational-Wave Observatory) group that made the first detection of gravitational waves in 2015. Scientists from the Space Research Centre at the University of Leicester have been working on the Mid InfraRed Instrument (MIRI) on board the James Webb Space Telescope. Spend time looking at what each university has to offer.

Learn from experience

Work experience schemes such as Space Placements in INdustry (SPIN) enable you to learn new skills and try a career on for size. Graduate training schemes are an excellent way to get into the space industry and launch your career, while learning valuable skills. Examples include ESA's Young Graduate Trainee Programme (YGT) and schemes with aerospace companies such as Airbus, QinetiQ, RAL Space and Surrey Satellite Technology Ltd (SSTL).

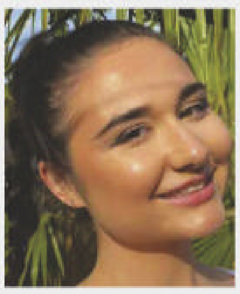
The growth of the space sector depends on people with the right skills entering the industry, and apprenticeship schemes help ensure that people with those skills are there to drive the industry forward. Apprentices receive on-the-job training while being paid for work, and study for at least 20 per cent



▲ **Scientists from the University of Leicester have worked on one of the instruments that will be used on the James Webb Space Telescope**

LIGO/T. PYLE, JOHN GAFFEN/ALAMY STOCK PHOTO, STEPHEN KILL/STFC, ESA

EMPLOYEE PROFILE



Chloe Smith • Job title: Apprentice at Surrey Satellite Technology Ltd (SSTL)

Chloe assesses spacecraft parts to ensure they can withstand space radiation.

"If you're not top of the class in your favourite subject, don't let that put you off. If you have a passion for something, you can make it happen. Having a strong interest in something is more important than being amazing at it. At the end of the day, no one knows everything and you'll learn along the way."

EMPLOYEE PROFILE

Tim Peake • Job title: Astronaut

Tim is the UK's first ESA astronaut and is heavily engaged in spaceflight outreach.

"Get involved in science, tech and engineering. It doesn't matter if you want a career in science or art: you're going to be working with technology. If you study those subjects, you're setting yourself up well for the future, giving yourself the maximum opportunity. But find out what you're passionate about: that's what you're going to be really good at."

of their working hours (usually one day a week), gaining skills and knowledge needed for the job. Apprenticeships usually last between one and six years and are available at different levels, so you can choose one to suit you and your qualifications. UK organisations offering apprenticeships include Airbus, Rolls-Royce, QinetiQ, SSTL, Reaction Engines, RAL Space and the National Space Academy.

Hayley Smith is a physics teacher and a Lead Educator at the National Space Academy

Support for students

UK Students for the Exploration and Development of Space (UKSEDS) is the UK's national student space society. It provides training and events for students with an interest in space. UKSEDS has a careers hub (**spacecareers.uk**) with details of jobs and internships, interviews with people working in the sector and resources to help you map out a career path. If you're after a direct-entry job, it's a great place to start.

Summer schools, such as Space School UK, run programmes for young people with an interest in space science. Many schools have a STEM (Science, Technology, Engineering and Maths) club that gives you a chance to develop skills and meet like-minded people. Studying subjects such as GCSE Astronomy, taking part in competitions like the UK Space Design Competition and getting involved in projects like the National Schools Observatory are all great ways to boost your knowledge and skills.

With many innovative space and astronomy missions on the horizon, new UK spaceports being constructed and humans set to return to the Moon to build the Lunar Gateway, it's an exciting time for astronomy and space exploration. The question is will you be a part of it?

BBC Bitesize

BBC Bitesize is a free online resource designed to help with careers and learning. There's a range of interactive lessons, video clips and quizzes to help boost your knowledge in all subjects, including physics and space science, as well as a huge range of careers resources including job profiles, interviews and CV writing tips. See more at **www.bbc.co.uk/bitesize**

▲ ESA's YGT (Young Graduate Trainee) Programme offers students a chance to gain valuable experience in space mission operations

BBC Sky at Night MAGAZINE

MASTERCLASS

ASTROPHOTOGRAPHY SERIES

To give you your best start in photographing the night sky, we're running our first online Masterclass: the Astrophotography Series. This three-part series of talks will arm you with the knowledge and methods for taking stunning images of the night sky with a smartphone, a DSLR camera and specialist astro cameras. Whether you're new to astrophotography or a seasoned imager, there's always something to learn and our online masterclasses are the perfect way to pick up tips, hints and a raft of skills. All registrants will also receive a link to view a recording of each Masterclass after it has aired. You can book each Masterclass individually for £15 or save 20 per cent by booking all three at once.

Join host and Editor Chris Bramley for the three-part series of online masterclasses on astrophotography, featuring these three expert guests

M-GUCCI/ISTOCK/GETTY IMAGES, MATT_GIBSON/ISTOCK/GETTY IMAGES, PETER JENKINS

Masterclass 1

Capture the night sky with your smartphone

Tom Kerss

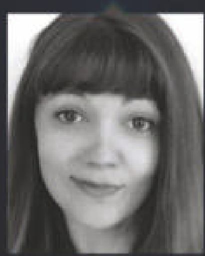
Join us to discover how to capture the night sky with your smartphone. We'll look at suitable targets and top apps to try out.

Thursday 23 September, 7pm BST

Masterclass 2

Night sky photography with a DSLR camera

Charlotte Daniels



If you want to turn a DSLR camera to the stars, this is the talk for you. We'll look at taking nightscapes and star fields, equipment and processing.

Thursday 28 October, 7pm BST

Masterclass 3

Imaging the deep sky from towns and cities

Peter Jenkins

We'll look at how you can cut through urban sky glow with a scope and a specialist astro camera, and how processing can help even further.

Thursday 25 November, 7pm GMT

Save 20% when you book the series of all three masterclasses

Visit **skyatnightmagazine.com/virtual-events** to find out more and book

16-PAGE CENTRE PULLOUT

BBC Sky at Night MAGAZINE

The Sky Guide

SEPTEMBER 2021

HUNT FOR THE SLENDER MOON

Two excellent opportunities this month, thanks to a good phase and position

MINOR PLANET AHOY

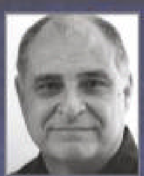
Observe asteroid 2 Pallas as it reaches opposition in Pisces

LOCATE A 'LUNAR CITY'

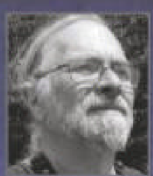
Spot the streets of Gruithuisen's imaginary metropolis

PETE LAWRENCE

About the writers



Astronomy expert **Pete Lawrence** is a skilled astro imager and a presenter on *The Sky at Night* monthly on BBC Four



Steve Tonkin is a binocular observer. Find his tour of the best sights for both eyes on page 54

Also on view this month...

- Shadow transits by Jupiter's Galilean moons
- Mercury at greatest eastern elongation
- A conjunction of Jupiter, Saturn and the Moon

Red light friendly

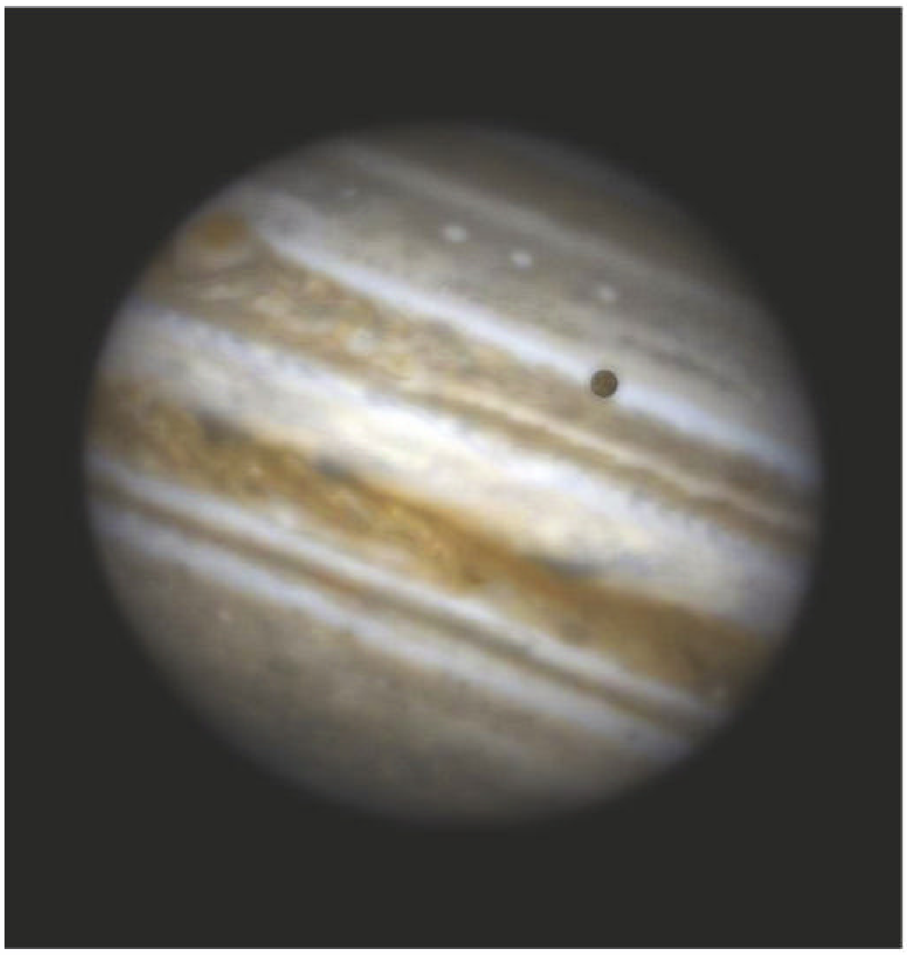
To preserve your night vision, this Sky Guide can be read using a red light under dark skies

Get the Sky Guide weekly

For weekly updates on what to look out for in the night sky and more, sign up to our newsletter at **www.skyatnightmagazine.com**

SEPTEMBER HIGHLIGHTS

Your guide to the night sky this month



◀ Wednesday 1

A telescopic view of Jupiter this morning will reveal the outer Galilean moon, Callisto, transiting the planet's disc from 02:33 BST (01:33 UT). Jupiter sets before the transit ends. See page 47 for more.

Thursday 2

This morning's 24%-lit waning crescent Moon occults mag. +3.0 Mebsuta (Epsilon (ε) Geminorum) from 01:12 BST (00:12 UT) until 02:04 BST (01:04 UT). These times are correct for the centre of the UK and will vary slightly with location.

Monday 6 ▶

There's an excellent opportunity to spot a less than 1%-lit thin crescent Moon this morning. It is located 5.6˚ to the left of, and fractionally down from, Regulus (Alpha (α) Leonis). The Moon rises 75 minutes before the Sun. See page 46 for more.

◀ Friday 10

Around midnight BST (23:00 UT), extend the east side of the Great Square of Pegasus (left from the UK) down to locate bright Deneb Kaitos (Beta (β) Ceti). 7.3˚ south and a fraction east of this star lies a treat – the mag. +7.1 Sculptor Galaxy.

Saturday 11

Asteroid 2 Pallas reaches opposition today in the constellation of Pisces, the Fishes. Shining at mag. +8.5, 2 Pallas is a viable binocular target. Turn to page 53 for more.

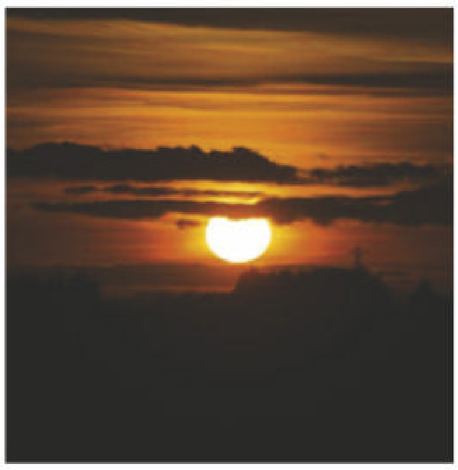
Tuesday 14 ▶

Mercury reaches greatest eastern elongation. Today, it will appear separated from the Sun by 26.8˚ in the evening sky. Poor positioning means mag. +0.3 Mercury will set 20 minutes after the Sun.

Neptune reaches opposition.

Family stargazing

The 'Lunar X' and 'Lunar V' are examples of clair-obscur effects; tricks of light and shadow which creates familiar shapes. In this case, it's the letters X and V that appear along the line dividing light and dark on the Moon's globe – the terminator. Visible for just a few hours, both letters are best seen at 21:30 BST (20:30 UT) on 13 September, the 'X' roughly one-quarter up the terminator from the Moon's southern edge, the 'V' slightly north of the mid-point. Using binoculars or a scope, can you see the letters suspended in the dark against the terminator? **www.bbc.co.uk/cbeebies/shows/stargazing**



◀ Wednesday 22

At 20:21 BST (19:21 UT) the centre of the Sun's disc crosses the celestial equator moving from north to south. This instant in time is known as an equinox and for the Northern Hemisphere it marks the start of autumn.

PETE LAWRENCE X 7

Friday 3

This morning's 16%-lit waning crescent Moon occults mag. +3.6 Kappa (κ) Geminorum from 03:41 BST (02:41 UT) until 04:38 BST (03:38 UT).

Saturday 4

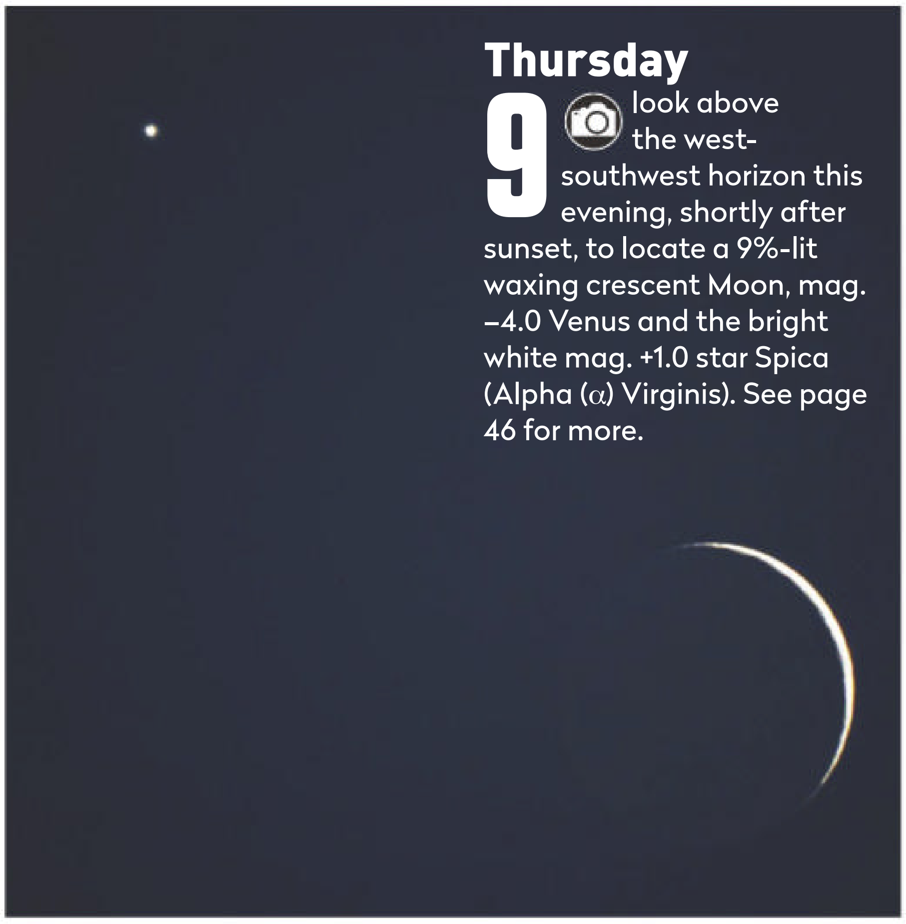
This morning's 9%-lit waning lunar crescent is just 2.6° from the Beehive Cluster, M44, at 04:10 BST (03:10 UT).

Sunday 5

Catch two good transits by Jupiter's moons and their shadows. Europa begins to transit at 23:12 BST (22:12 UT), followed by its shadow at 00:04 BST (23:04 UT). Ganymede starts to transit at 02:03 BST (01:03 UT), on 6 September, its shadow following at 03:47 BST (02:47 UT). See page 47.

Tuesday 7

There's another opportunity to spot an ultra-thin Moon this evening. Look low down above the western horizon after sunset to spot this less than 1%-lit waxing crescent. It will set about 35 minutes after the Sun. See page 46 for more.



Thursday 9

look above the west-southwest horizon this evening, shortly after sunset, to locate a 9%-lit waxing crescent Moon, mag. –4.0 Venus and the bright white mag. +1.0 star Spica (Alpha (α) Virginis). See page 46 for more.

Monday 13

A telescopic view of this evening's first quarter Moon around 21:30 BST (20:30 UT) will reveal the clair-obscur effects known as the 'Lunar X' and 'Lunar V'; two giant letter shapes floating next to the lunar terminator.

Friday 17

At 22:30 BST (21:30 UT) an 89%-lit waxing gibbous Moon is near Saturn and Jupiter.

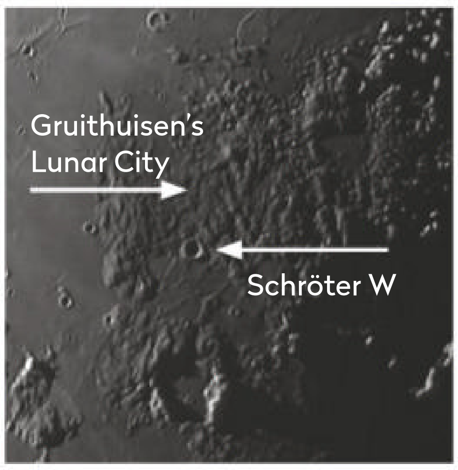
A shadow transit of Jupiter's disc by its moon Callisto starts at 23:43 BST (22:43 UT). See page 47 for more.

Monday ▶ 20

Today's full Moon is the closest full Moon to the Northern Hemisphere's autumn equinox. Consequently, this will be the Harvest Moon for 2021.

Monday 27

Catch a daylight shadow transit of Ganymede from 15:49 BST (14:49 UT) until 19:25 BST (18:25 UT). The end of the event occurs in darkening evening twilight. See to page 47 for more.



◀ Wednesday 29

Viewing the last quarter Moon with a scope this morning, can you spot what was once believed to be a ruined city? The clair-obscur effect known as 'Gruithuisen's Lunar City' is visible, north of crater Schröter W. See page 47 for more.

NEED TO KNOW

The terms and symbols used in The Sky Guide

Universal Time (UT) and British Summer Time (BST)

Universal Time (UT) is the standard time used by astronomers around the world. British Summer Time (BST) is one hour ahead of UT

RA (Right ascension) and dec. (declination)

These coordinates are the night sky's equivalent of longitude and latitude, describing where an object is on the celestial 'globe'

Family friendly
Objects marked with this icon are perfect for showing to children

Naked eye
Allow 20 minutes for your eyes to become dark-adapted

Photo opp
Use a CCD, planetary camera or standard DSLR

Binoculars
10x50 recommended

Small/medium scope
Reflector/SCT under 6 inches, refractor under 4 inches

Large scope
Reflector/SCT over 6 inches, refractor over 4 inches

GETTING STARTED IN ASTRONOMY

If you're new to astronomy, you'll find two essential reads on our website. Visit **http://bit.ly/10_easylessons** for our 10-step guide to getting started and **http://bit.ly/buy_scope** for advice on choosing a scope

THE BIG THREE

The three top sights to observe or image this month

DON'T MISS

THE MOON

BEST TIME TO SEE: Multiple events, dates and times as specified

The Moon puts on a fine display of varied events during September. On the morning of the 2nd, starting at 01:12 BST (00:12 UT), the 24%-lit waning crescent Moon occults mag. +3.0 Mebsuta (Epsilon (ε) Geminorum) – when the Moon's position hides our view of the star from Earth. The star's reappearance occurs around 02:04 BST (01:04 UT), as viewed from centre of the UK, although times will vary slightly with location. On the morning of the 3rd, mag. +3.6 Kappa (κ) Geminorum is occulted by the now 16%-lit waning crescent Moon. Viewed from the centre of the UK, it disappears at 03:41 BST (02:41 UT), and reappears at 04:38 BST (03:38 UT) in morning twilight.

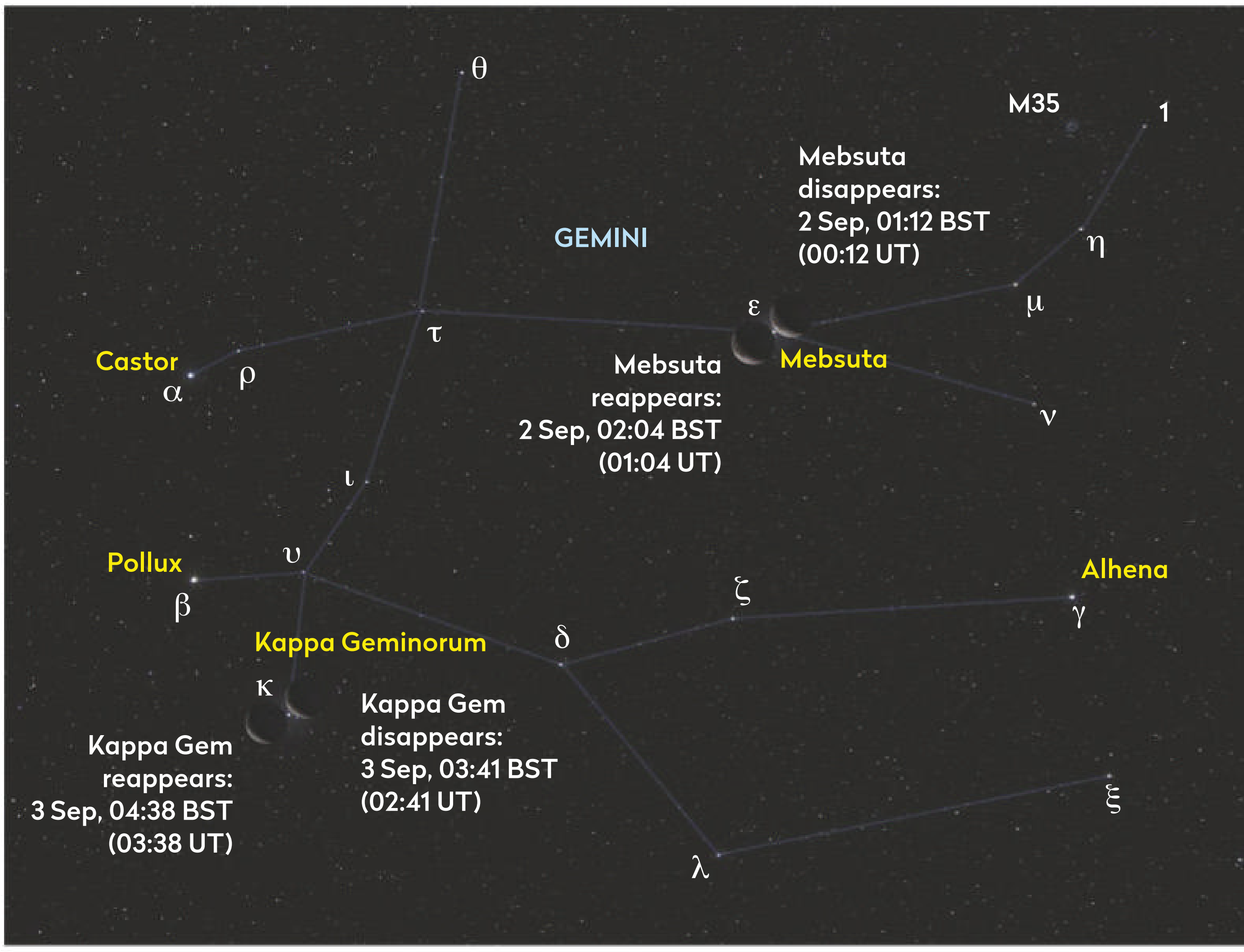
On the morning of 4 September, now at a 9%-lit waning crescent phase, the Moon lies close to the beautiful Beehive Cluster, M44, in Cancer, the Crab. At 04:10 BST (03:10 UT) the centre of the Moon sits 2.6° from the centre of the open cluster.

The Moon appears as an ultra-thin crescent on the morning of 6 September and the evening of the 7th, visible against the bright vignette of the dawn and dusk sky. On the morning of the 6th, the 1%-lit waning crescent Moon rises 75 minutes before the Sun. The position for this challenging crescent couldn't be better, the Moon rising almost vertically above the position of the Sun. After passing new Moon at 01:15 BST (00:15 UT) on the 7th, that evening there's an opportunity to spot the ultra-thin waxing, crescent Moon after sunset. The position of this Moon isn't so optimal, and although this thin lunar crescent is slightly further from the Sun in the sky than it was on the morning of the 6th, it will set just 40 minutes after the Sun.

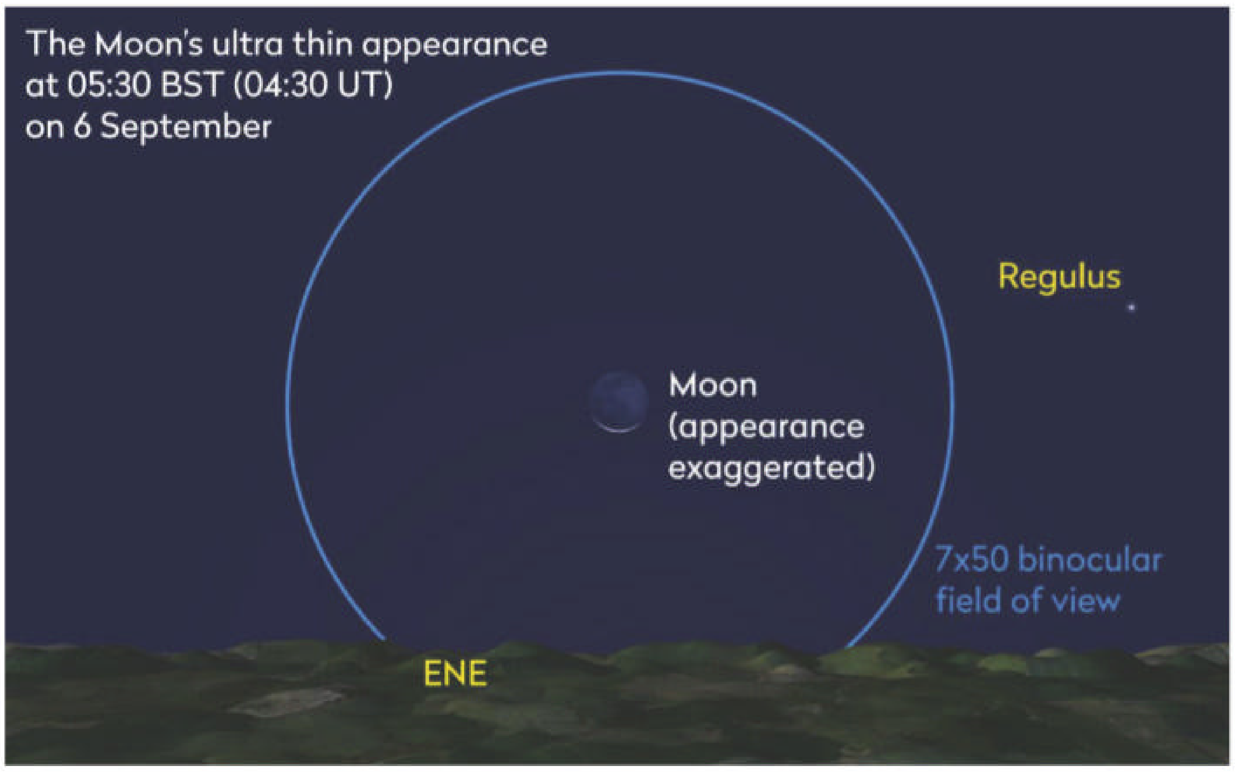
Two nights later on 9 September, it's possible to see a now 9%-lit waxing crescent Moon located approximately 6° from mag. –4.0 Venus, low in the west-southwest after sunset. The two objects form an interesting down-pointing triangle with mag. +1.0 Spica (Alpha (α) Virginis), located close to the horizon below the Moon and Venus.

On the evening of the 13th, a telescopic view of the Moon at 21:30 BST (20:30 UT) reveals the popular 'Lunar X' and 'Lunar V' clair-obscur effects that appear near the terminator. The 'Lunar X' is caused by the partial lighting of the rims of the craters La Caille, Purbach and Blanchinus, and the 'Lunar V' appears near the crater Ukert. On 29 September, the less familiar and challenging clair-obscur effect known as 'Gruithuisen's Lunar City' is visible near the crater Schröter W (see opposite).

Finally, full Moon on 20 September occurs a couple of days before the Northern Hemisphere's autumn equinox, making it the Harvest Moon for 2021.



▲ The Moon occults Mebsuta (on 2 September) and Kappa Geminorum (on 3 September)



▲ Catch a 1%-lit waning crescent Moon rising 75 minutes before the Sun on 6 September

ALL PICTURES: PETE LAWRENCE

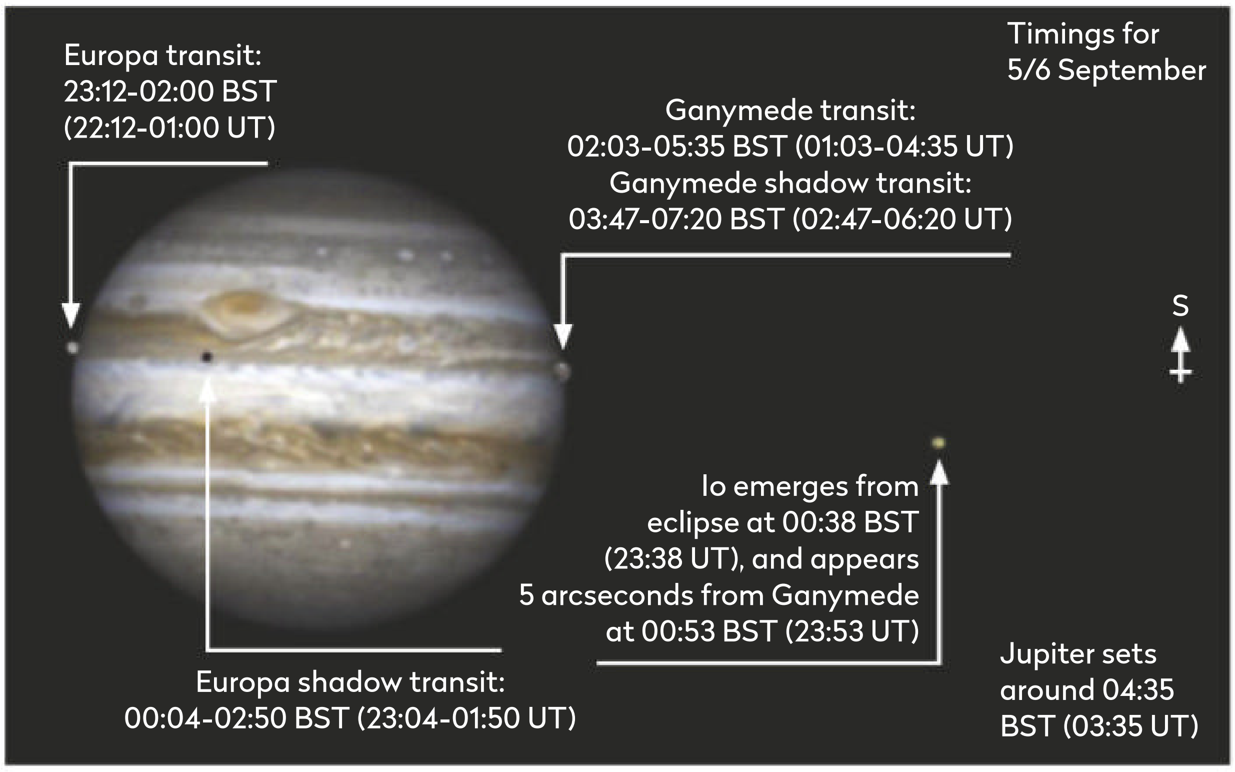
Galilean satellite events

BEST TIME TO SEE: Multiple events, dates and times as specified

Earth's Moon is not the only one to put on a show this month. Jupiter's moons are putting on something of a display too. The outer Galilean moon Callisto will be transiting Jupiter's disc on 1 September from 02:33 BST (01:33 UT) until Jupiter sets. A few days later, starting on the evening of 5 September, there are two good satellite and shadow transits occurring in quick succession. The events start at 23:12 BST (22:12 UT) with Europa's transit followed by its shadow at 00:04 BST (23:04 UT). Ganymede starts to transit at 02:03 BST (02:03 UT) followed by its own shadow at 03:47 BST (02:47 UT).

Callisto once again gives us a display on the 17th when its giant shadow can be seen crossing Jupiter's disc in a well-timed event for UK viewing. The event starts at 23:43 BST (22:43 UT), but concludes shortly after Jupiter sets. Jupiter hits the west-southwest horizon around 03:55 BST (02:55 UT) giving plenty of time to take in the best parts of this least common of all the Galilean moon shadow transits. Callisto's shadow is more or less central on Jupiter's disc around 01:44 BST (00:44 UT), when Jupiter will have an altitude around 14° above the southwest horizon. An 89%-lit waxing gibbous Moon sits below the gas giant, forming a triangle with Jupiter and Saturn.

A transit of Ganymede's shadow occurs on the 27th. Most of this event occurs before Jupiter rises, with the shadow over the halfway point under daylight conditions as Jupiter appears. Catch it before 19:25 BST (18:25 UT) and see the shadow as it nears Jupiter's western limb.



▲ **A south-up view of transit activity on Jupiter at 02:00 BST (01:00 UT) on 6 September**

Gruithuisen's Lunar City

BEST TIME TO SEE: 29 September from 05:00 BST (04:00 UT)

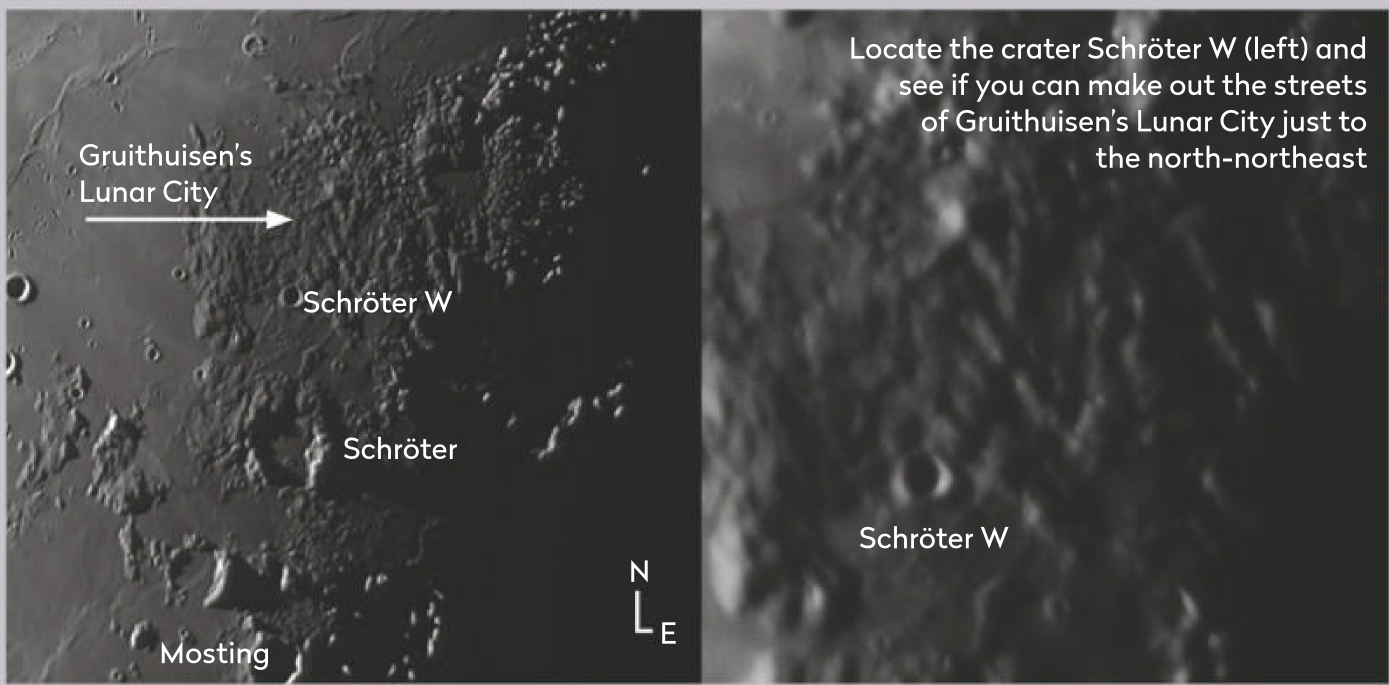
There's an opportunity to spot the less common clair-obscur effect known as Gruithuisen's Lunar City on the morning of the 29th. With such an enigmatic sounding name you might expect the view through a telescope eyepiece to be grandiose, but it's not!

The 'city' is formed by subtle light and shadow play, which can be hard to see. Of course, this makes it an irresistible astronomical challenge.

It's possible to navigate to the 'city' via several distinctive craters, including 93km Copernicus and 60km Eratosthenes. Imagine them forming one side of a large isosceles triangle. The southern vertex close to the morning terminator, is marked by 27km Mosting.

From Mosting, head back towards Eratosthenes. Roughly one-fifth the way you'll encounter heavily eroded 35km Schröter. Keep travelling towards Eratosthenes and the next small identifiable crater is 10km Schröter W with a smaller crater, 3km Schröter A, inside it. The 'streets' of Gruithuisen's city appear to radiate north of Schröter W in a fan-like arrangement.

The effect is named after astronomer Franz von Paula Gruithuisen who discovered the 'Lunar City' in 1824.



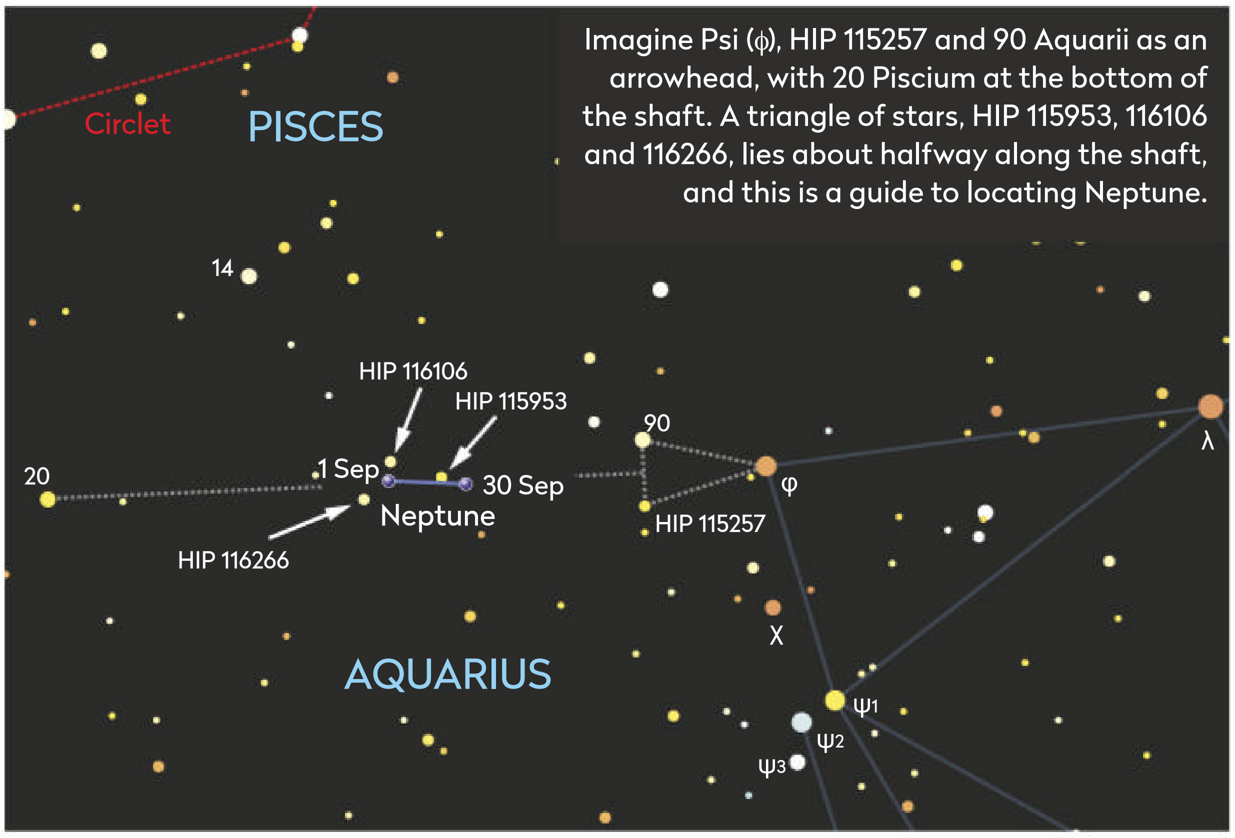
Locate the crater Schröter W (left) and see if you can make out the streets of Gruithuisen's Lunar City just to the north-northeast

THE PLANETS
Our celestial neighbourhood in September

PICK OF THE MONTH

Neptune

Best time to see: 14 September, 01:00 BST (00:00 UT)
Altitude: 33°
Location: Aquarius
Direction: South
Features: Small blue-hued disc, atmospheric features
Recommended equipment: 200mm or larger



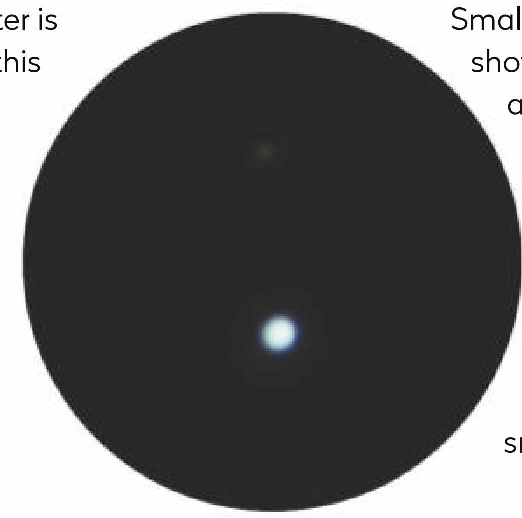
Imagine Psi (φ), HIP 115257 and 90 Aquarii as an arrowhead, with 20 Piscium at the bottom of the shaft. A triangle of stars, HIP 115953, 116106 and 116266, lies about halfway along the shaft, and this is a guide to locating Neptune.

Under the current definition of a planet, Neptune is the farthest such object in our Solar System. It orbits the Sun at a distance of 4.5 billion kilometres, taking 164.8 years to complete each orbit. It was discovered by Johann Galle and Urban Le Verrier on 23 September 1846 and as such has only completed one orbit around the Sun since its discovery. Neptune is the only main planet not visible to the naked eye, although its Solar System neighbour, Uranus, is hardly easy in this respect!

Neptune is currently located in Aquarius, roughly midway between mag. +4.2 Psi (φ) Aquarii and mag. +5.5 20 Piscium. Binoculars will show it to look exactly like a mag. +7.8 star, but its planetary nature becomes more evident through the eyepiece of a telescope. Neptune shows a tiny 2 arcsecond disc.

A power of 200x or greater is recommended to show this disc well. The planet's colour, like the green hue of Uranus, is quite striking, Neptune being noticeably blue.

Neptune reaches opposition on the 14th although being so distant, this optimal position in the sky doesn't make a great deal of difference to the planet's overall appearance. It does mean it's up all night long though, so this is as good a time as ever to look for it.

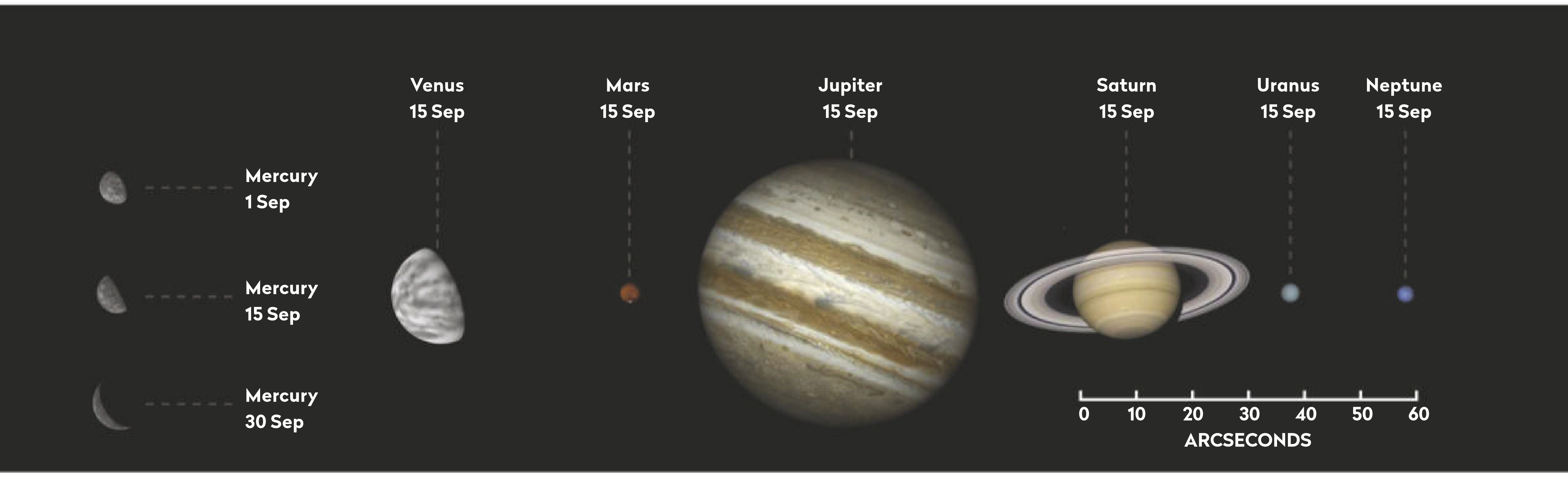

▲ **When Neptune reaches opposition on 14 September, it will be visible all night long**

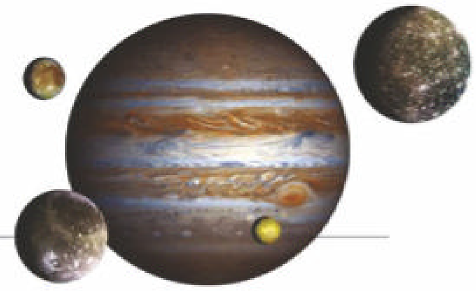
Smaller instruments will show the planet's blue disc as described, but may also be able to pick out Neptune's largest moon, Triton. Shining at mag. +13.5, Triton is an easy catch for a 300mm instrument, but isn't out of range of smaller scopes; 200mm is probably the minimum. Larger scopes fitted with specialist high-resolution imaging kit may occasionally pick out large detail on Neptune's disc such as atmospheric banding and storm systems.

PETE LAWRENCE X 3

The planets in September

The phase and relative sizes of the planets this month. Each planet is shown with south at the top, to show its orientation through a telescope





Mercury

Best time to see: 1 September, 15 minutes after sunset
Altitude: 2˚ (very low)
Location: Virgo
Direction: West

Mercury is an evening object during September, but its position deteriorates over the month. Your best chance of spotting it will be on the 1st when, shining at mag. 0.0, it sets 30 minutes after the Sun, below the western horizon. This doesn't give you long to locate it. Venus is also low in this direction, 16˚ east of Mercury's position. By the end of the month, mag. +1.5 Mercury virtually sets with the Sun.

Venus

Best time to see: 1 September, from 20 minutes after sunset
Altitude: 5˚ (low)
Location: Virgo
Direction: West-southwest

Venus is visible in the evening sky after sunset, appearing higher than Mercury and much brighter. At the start of the month Venus shines at mag. –4.0. By the end of the month it increases in brilliance to mag. –4.2. Venus sets approximately 1 hour after the Sun throughout the month.

Given a flat west-southwest horizon, it may be possible to spot Spica (Alpha (α) Virginis) 1.6˚ below Venus on the evening of the 5th.

Mars

Shining with a magnitude of +1.8, Mars isn't really a viable target this month as it is too close to the Sun to be seen.

Jupiter

Best time to see: 1 September, 00:20 BST (23:20 UT)
Altitude: 22.9˚
Location: Capricornus
Direction: South

Jupiter is an evening planet, managing to achieve its highest position in the sky, due south, in darkness during the month. It's apparent position in the sky has it travelling west through the eastern part of Capricornus, the Sea Goat and this will reduce its overall altitude over the month. On the 1st, from the centre of the UK, Jupiter attains an altitude of 22.9˚. By the 30th, this value will have dropped to 22.0˚.

Saturn

Best time to see: 1 September, 23:10 BST (22:10 UT)
Altitude: 18˚
Location: Capricornus
Direction: South

Being at opposition at the start of August and with the rapidly expanding nights that occur during September, Saturn remains nicely placed, able to attain its maximum altitude of around 18˚ from the centre of the UK under dark sky conditions all month long. On the 1st, mag. +0.3 Saturn reaches its highest point in the sky, due south, at 23:10 BST (22:10 UT). By the month's end, this position is reached at 21:10 BST (20:10 UT).

Uranus

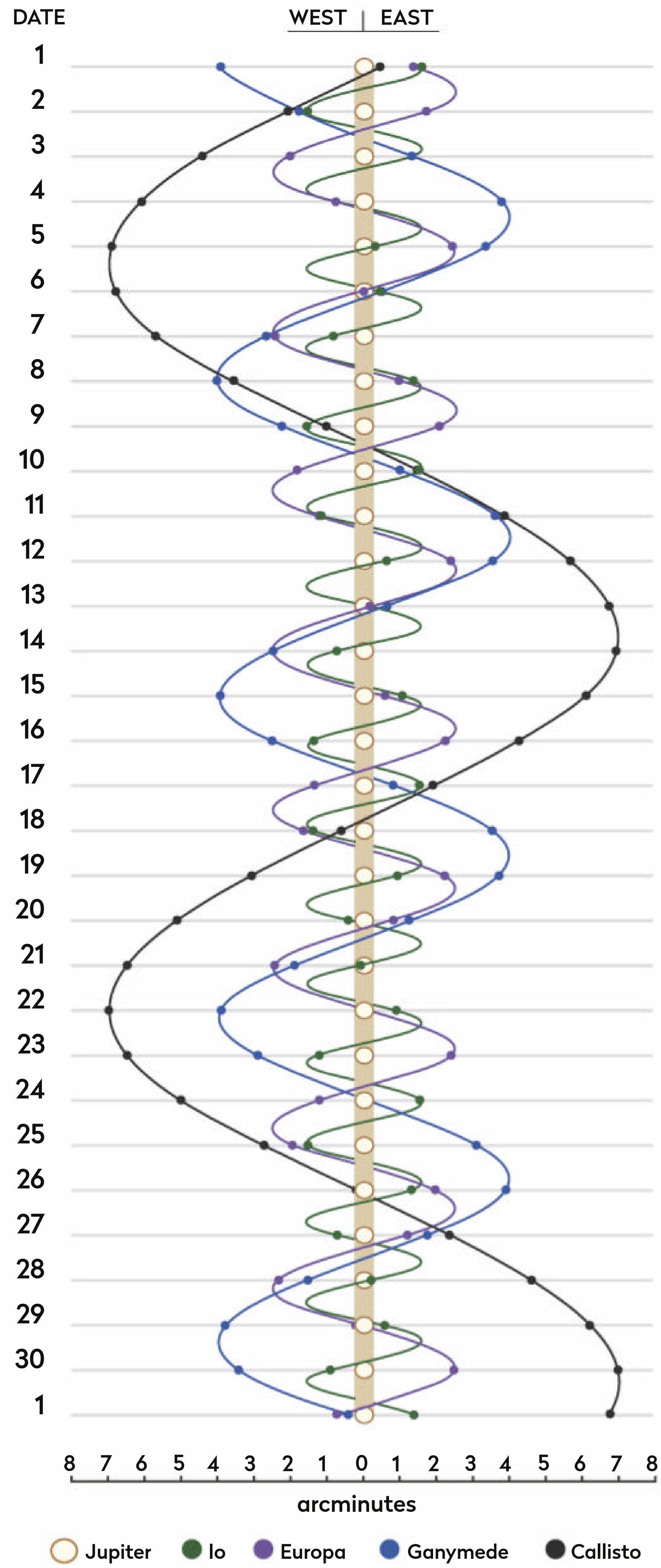
Best time to see: 30 September, 03:15 BST (02:15 UT)
Altitude: 53˚
Location: Aries
Direction: South

Uranus is well placed, reaching a position of 50˚ in total darkness in the morning sky. It currently resides in Aries, the Ram and is not too far from the Pleiades open cluster, the cluster being 16˚ east-northeast of Uranus. By the month's end, Uranus reaches a maximum height of 52˚ in darkness when due south as seen from the centre of the UK.

More ONLINE
Print out observing forms for recording planetary events

JUPITER'S MOONS: SEP

Using a small scope you can spot Jupiter's biggest moons. Their positions change dramatically during the month, as shown on the diagram. The line by each date represents 01:00 BST (00:00 UT).



THE NIGHT SKY – SEPTEMBER

Explore the celestial sphere with our Northern Hemisphere all-sky chart

KEY TO STAR CHARTS

- Arcturus — STAR NAME
- PERSEUS — CONSTELLATION NAME
- GALAXY
- OPEN CLUSTER
- GLOBULAR CLUSTER
- PLANETARY NEBULA
- DIFFUSE NEBULOSITY
- DOUBLE STAR
- VARIABLE STAR
- THE MOON, SHOWING PHASE
- COMET TRACK
- ASTEROID TRACK
- STAR-HOPPING PATH
- METEOR RADIANT
- Circlet — ASTERISM
- PLANET
- QUASAR

STAR BRIGHTNESS:

- MAG. 0 & BRIGHTER
- MAG. +1
- MAG. +2
- MAG. +3
- MAG. +4 & FAINTER
- 5° N E W S — COMPASS AND FIELD OF VIEW
- MILKY WAY

CHART: PETE LAWRENCE

When to use this chart

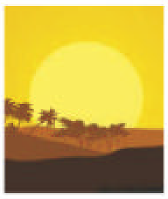
1 September at 01:00 BST
15 September at 00:00 BST
30 September at 23:00 BST

On other dates, stars will be in slightly different positions because of Earth's orbital motion. Stars that cross the sky will set in the west four minutes earlier each night.

How to use this chart

1. Hold the chart so the direction you're facing is at the bottom.
2. The lower half of the chart shows the sky ahead of you.
3. The centre of the chart is the point directly over your head.

Sunrise/sunset in September*



Date	Sunrise	Sunset
1 Sep 2021	06:19 BST	19:59 BST
11 Sep 2021	06:37 BST	19:35 BST
21 Sep 2021	06:54 BST	19:11 BST
01 Oct 2021	07:12 BST	18:46 BST

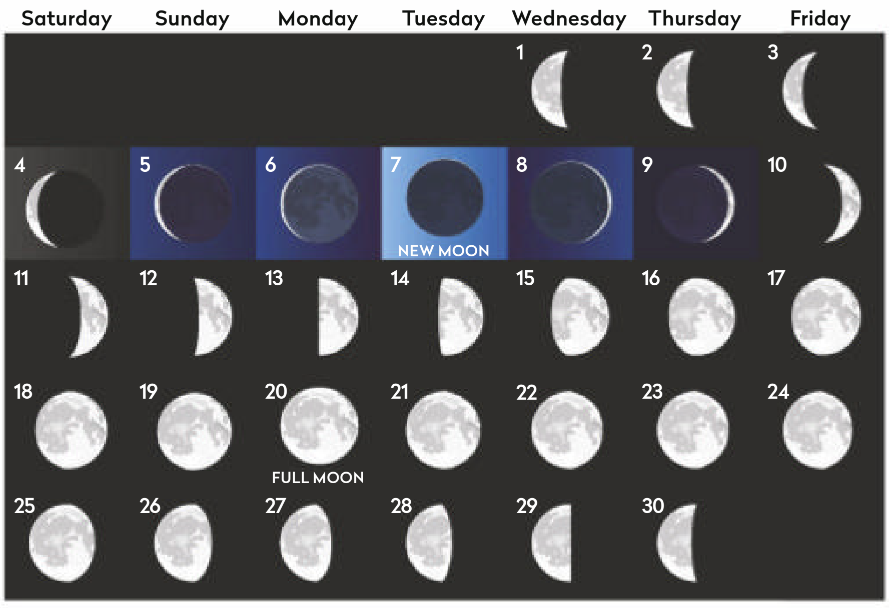
Moonrise in September*

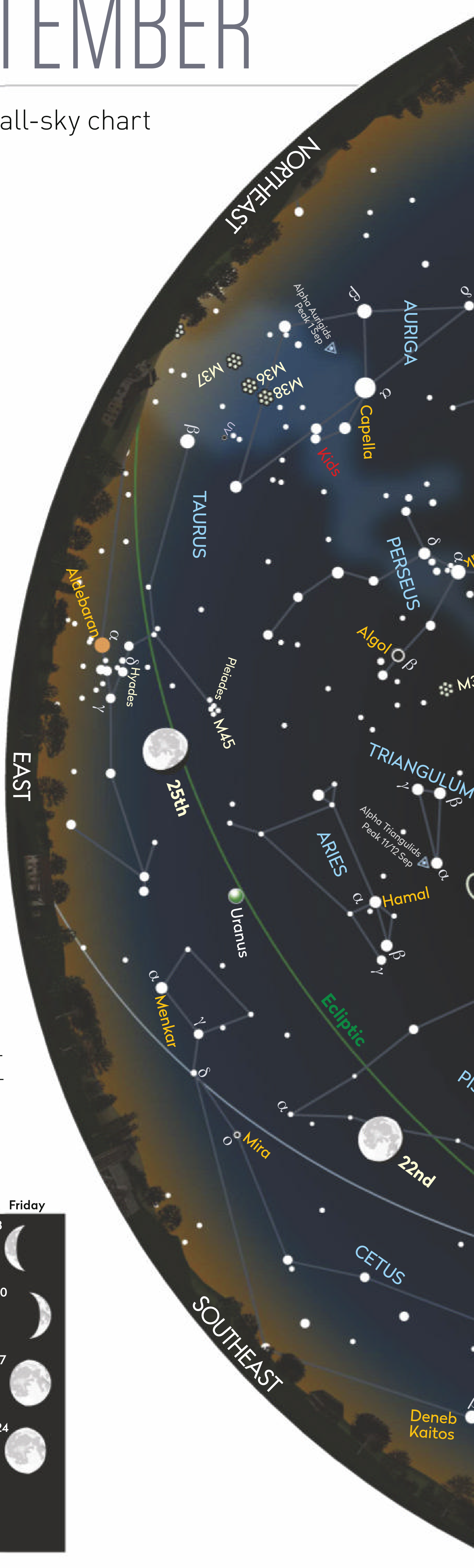
Moonrise times

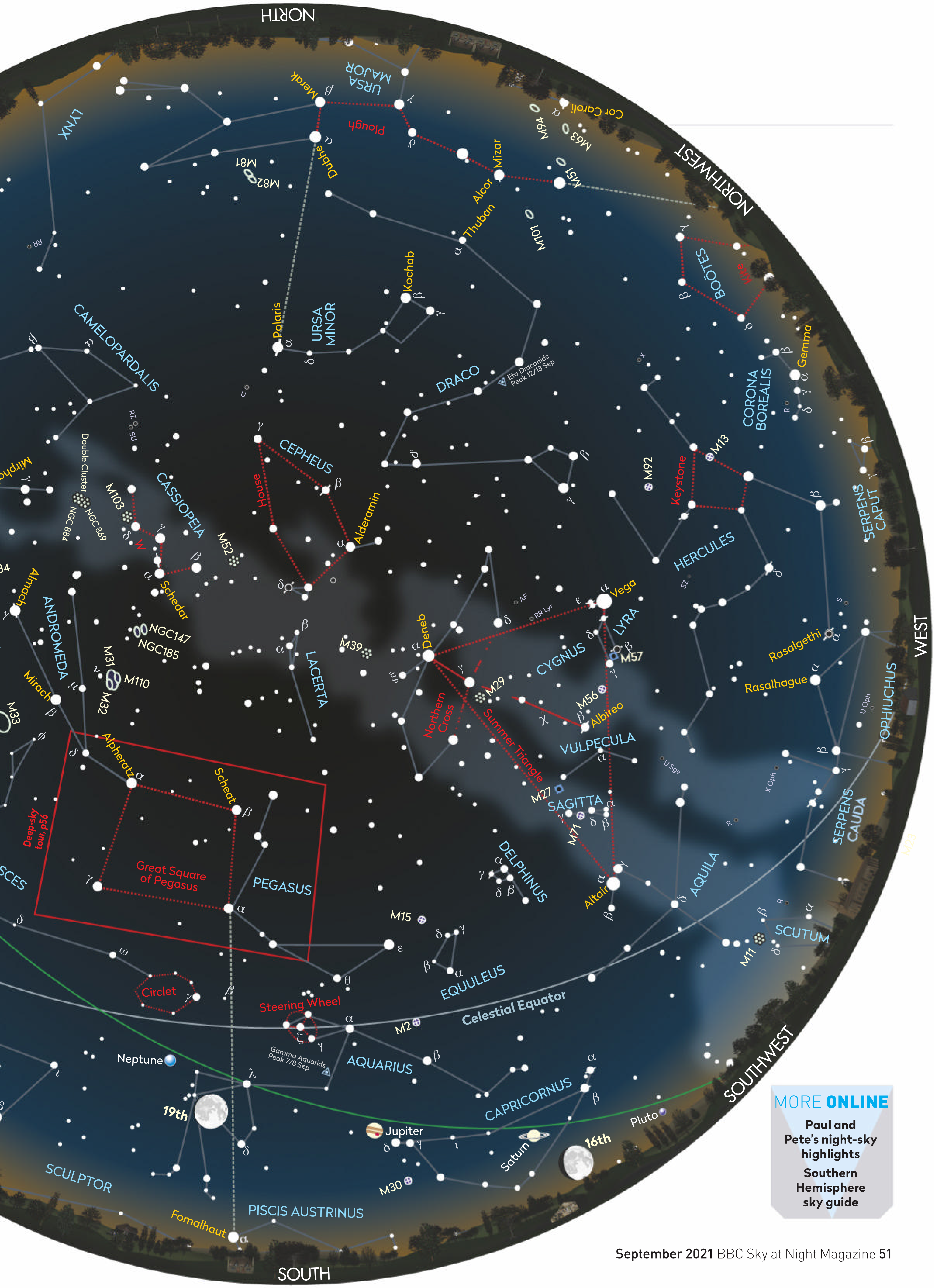
1 Sep 2021, --:-- BST	17 Sep 2021, 18:44 BST
5 Sep 2021, 03:48 BST	21 Sep 2021, 19:47 BST
9 Sep 2021, 09:23 BST	25 Sep 2021, 20:42 BST
13 Sep 2021, 15:13 BST	29 Sep 2021, 23:04 BST

*Times correct for the centre of the UK

Lunar phases in September







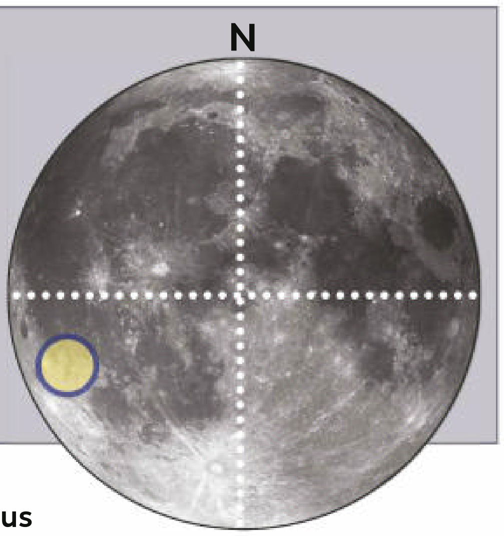
MORE **ONLINE**

Paul and Pete's night-sky highlights

Southern Hemisphere sky guide

Billy

Type: Crater
Size: 46km
Longitude/Latitude: 50.2˚W, 13.8˚S
Age: 3.2–3.9 billion years
Best time to see: Four days after first quarter (18 September) or three days after last quarter (3 September)
Minimum equipment: 50mm telescope



Located on the southern shore of **Oceanus Procellarum**, crater **Billy** may be only 46km in diameter but it has presence due to its dark, lava-filled floor. To the north and slightly west of Billy is 45km **Hansteen** a crater of similar size but completely different appearance. Where Billy's floor has been completely smoothed over by lava, Hansteen's remains faithful to the original impact and appears rough, covered in a series of concentric rings infilled with hills.

At times of oblique illumination, Billy's 1.3km-high rim casts its shadow across the crater's floor, the dark flat lava surface acting like a screen. During the waxing gibbous phase, you'll have to wait about four hours for the Moon's terminator to creep from Billy, far enough west to begin revealing Hansteen. Under such illumination the craters find an equivalence, Hansteen's intricate inner structures creating a complexity of shadow which is a delight to observe.

However, as the Sun begins to climb in the sky as seen from the location of this pair, sunlight falls more squarely onto the lunar surface and the lengths of the shadows decrease. With fuller, high-angle illumination, Hansteen begins to camouflage itself well into its highland surroundings. However, Billy's dark floor – one of the darkest regions on the Moon's Earth-facing side – comes into its own, remaining prominently visible against its brighter surrounding environment.

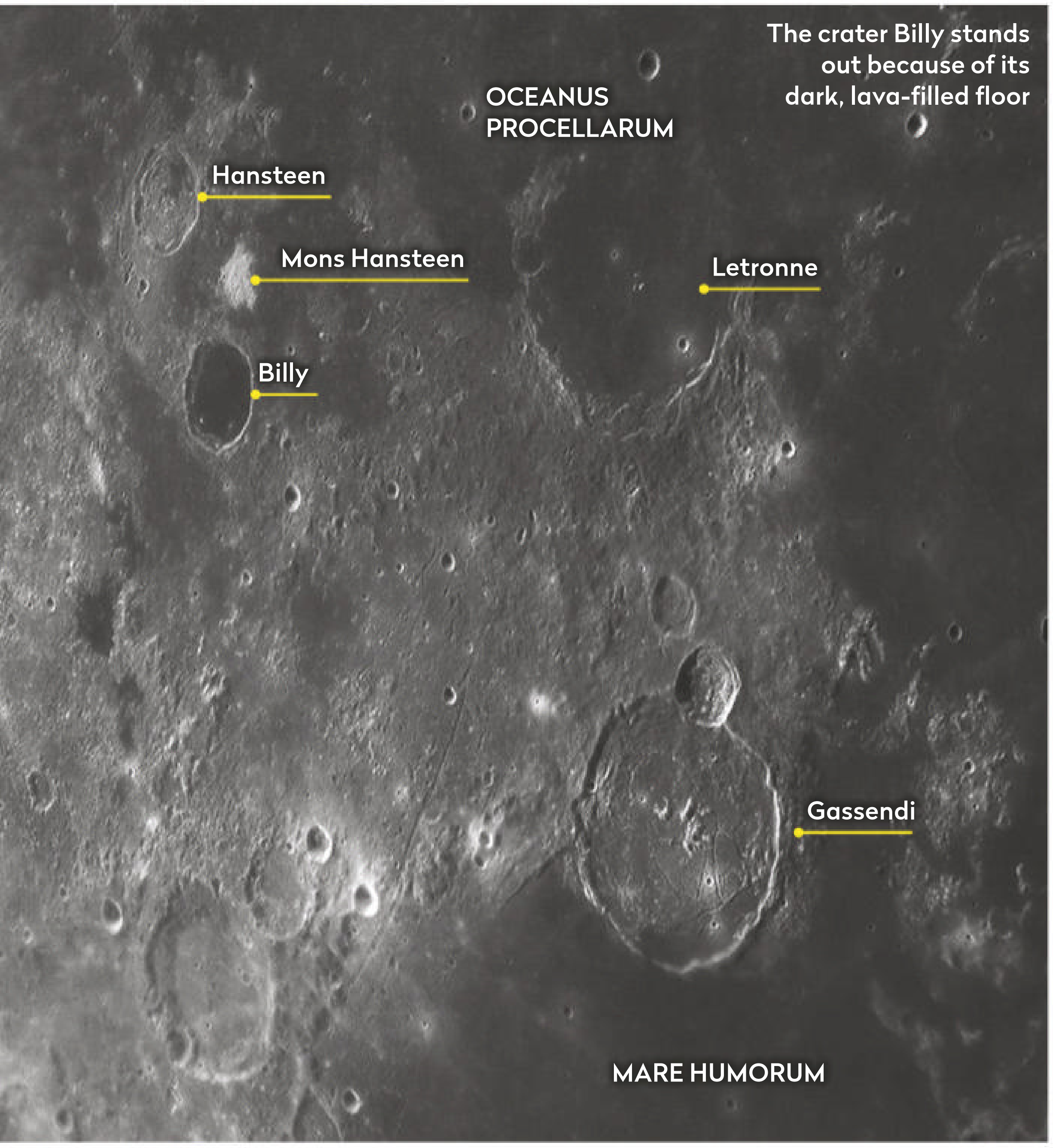
Billy's dark floor is one of the darkest regions on the Moon's Earth-facing side

Billy's floor looks remarkably smooth, the rim simply defining its outer boundary with no obvious incursions except, possibly to the south where an elevated shore has held the invading lava at bay. Two small craterlets can be seen in the southeast quadrant. Roughly 1.6km and 1.5km in diameter, like Billy itself, their east-west dimensions are squashed due to foreshortening, as a result of where Billy appears to sit on the Moon's globe as seen from Earth.

For those with large scopes or high-resolution imaging setups, there's a tiny craterlet in the southwest quadrant perhaps just 10-20 metres in diameter. Although far too small for Earth observation, the bright ejecta surrounding the craterlet is similar in size to the southeast quadrant craterlets. The bright ejecta material contrasts well against the dark lava which surrounds it. A tiny elevated hill sits to the north of this region and this too may be detectable under low light conditions.

Immediately north of Billy, and revealed at the same part of the Moon's phase-cycle is the triangular-shaped elevated region known as **Mons Hansteen**. This looks like a bright, north-pointing arrow, best seen when the terminator is nearby.

There are a lot of interesting features visible in this part of the Moon. Located 320km to the southeast is the 100km walled plain **Gassendi**, most noted for the complex rille (narrow channel) structures that criss-cross its floor. In contrast, 250km to the east-northeast is 120km **Letronne**, another lava-filled crater which has fared less well than Billy. Letronne keeps the part of its rim running from the northwest, through west, around south and up to the east, but the remainder is missing, submerged beneath the floor of the **Oceanus Procellarum**.



The crater Billy stands out because of its dark, lava-filled floor

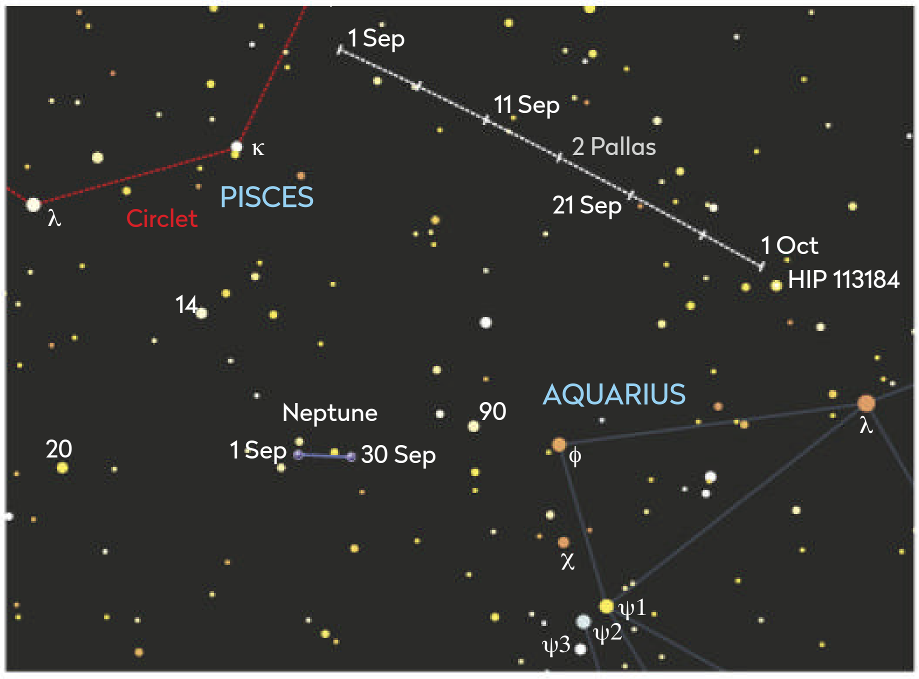
PETE LAWRENCE X 3

COMETS AND ASTEROIDS

View asteroid 2 Pallas as it reaches opposition in Pisces, the Fishes

Minor planet 2 Pallas is, as its prefix number suggests, the second minor planet discovered. It's one of the 'big four' asteroids which includes 1 Ceres (now re-classified as a dwarf planet), 3 Juno and 4 Vesta. They were discovered in close proximity to one another between 1 January 1801 and 29 March 1807. Amazingly, 5 Astraea wasn't discovered until 8 December 1845, breaking a long period where it was thought that 1-4 were the only such objects. To date, around one million asteroids have been observed and recorded. The four largest asteroids (in size order) are Ceres, Vesta, Pallas and Hygiea. The third discovery, 3 Juno, is the 10th largest. 2 Pallas is third largest with a mean diameter around 513km.

Pallas's discovery is attributed to Heinrich Olbers on 28 March 1802, but it was a close call. Charles Messier recorded it 23 years earlier while tracking a comet, but he thought it was a star and its identity remained hidden. In 1801, Giuseppe Piazzi discovered 1 Ceres. While initially believing it to be a comet, its motion was unlike any he'd seen before. After months being lost from sight, Ceres was recovered by Baron von Zach and Olbers later in 1801. It was while attempting to relocate Ceres a few months later, that Olbers found Pallas which was nearby in the sky.



▲ **Spot asteroid 2 Pallas as it passes from Pisces to Aquarius**

Pallas reaches opposition on the 11th when it can be seen at mag. +8.5 in Pisces, to the southwest of the faint Circlet asterism. It spends much of the month in Pisces, skipping into Aquarius at the end. Starting the month at mag. +8.8 and ending at mag. +8.9, Pallas is an easy target for a small scope. It's a B-type asteroid, part of the C-type class, but having a spectral bias towards blue.

STAR OF THE MONTH

Dabih, a western marker of Capricornus

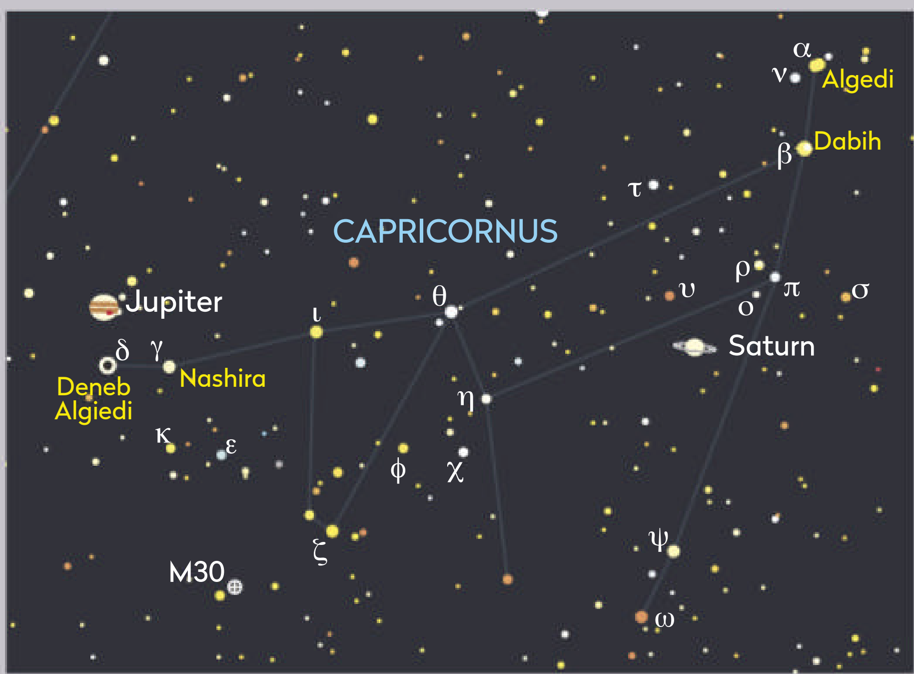
The constellation of Capricornus, the Sea Goat looks like a misshapen triangle. It's not the easiest pattern to make out, but thanks to some planetary crowding it's a little easier to locate at present; both Jupiter and Saturn currently reside there. Two distinguishing features of the main pattern are a pair of middle-bright stars marking the east and west ends of this down-pointing triangle. The pair at the western end, nearest Saturn, are Algedi (Alpha (α) Capricorni) and Dabih (Beta (β) Capricorni).

To the naked eye, Algedi looks double, but this is nothing more than a line-of-sight effect. In contrast, Dabih is a true binary, its companion a little closer than the 6.6 arcminute separation of Algedi, at just 3.4 arcminutes. In reality, the Dabih system is far more complex than it seems, comprising five stars in total. The brighter star shines at mag. +3.1 and is designated Beta^1 (β^1) or Beta (β) Capricorni A. The dimmer component shines at mag. +6.1 and is designated Beta^2 (β^2) or Beta (β) Capricorni B.

Beta Capricorni A is a triple system formed from a primary Aa and a binary pair Ab^1 and Ab^2. The separation between Aa and the Ab^1/Ab^2 pair is tiny at 0.05 arcseconds. Ab^1 and Ab^2 orbit one another over a period of 8.7 days. Aa is a K-type orange star, 35 times larger than our Sun. Ab^1 has an apparent magnitude of +7.2 and is a white B-type main sequence dwarf. The Ab^2 component remains unseen.

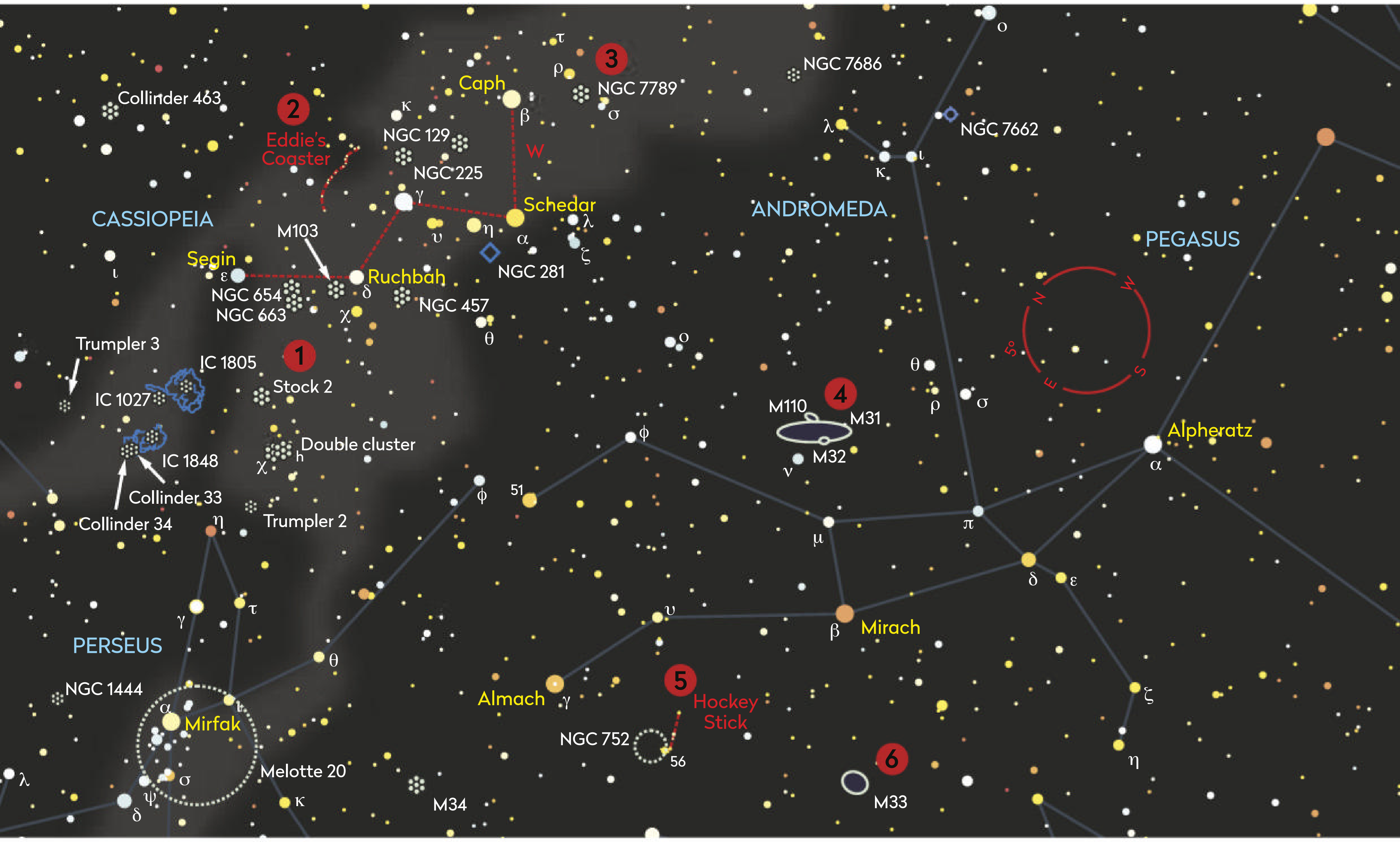
Beta Capricorni B, is also a binary pair, the components being designated Ba and Bb. The separation of this pair is larger at 3 arcseconds. Beta Capricorni Ba shines at mag. +6.1 and appears white in colour, an A0 giant star.

▼ **The name Dabih comes from the Arabic meaning "the butcher". The system is 328 lightyears away**



BINOCULAR TOUR With Steve Tonkin

From Eddie's Coaster to the Triangulum Galaxy, enjoy this month's wide-field targets



1. Muscleman Cluster

10x50 Start at Ruchbah (Delta (δ) Cassiopeiae) and pan 6.5° to the east, where you'll find a faint cluster of stars extending for more than 1°. This is Stock 2, the Muscleman Cluster, which gets its name from the sparse pattern of brighter stars that have the form of a stick man who is flexing his biceps in bodybuilder pose. The Muscleman is 1,050 lightyears away. ☐ **SEEN IT**

2. Eddie's Coaster

10x50 Eddie's Coaster is an asterism that is more obvious in 10x50 binoculars than just about anything else. Look 3° north of Gamma (γ) Cassiopeiae, where you will find this 3° long wave of 7th and 8th magnitude stars, reminiscent of a roller coaster. It was discovered by the late West Country amateur astronomer, Eddie Carpenter and listed in 2013. Cast around the Milky Way, and you too may discover a pattern of interest. ☐ **SEEN IT**

3. Caroline's Rose

15x70 You'll find our next object, NGC 7789, as its discoverer Caroline Herschel did in 1783, between Rho (ρ) and Sigma (σ) Cassiopeiae. Don't expect to be able to resolve any stars, even if you use averted vision. Even in 15x70 binoculars it appears as a soft glow, about half the apparent diameter of the Moon. With an age of a billion years, Caroline's Rose is unusually old for an open cluster. ☐ **SEEN IT**

4. The Andromeda Galaxy, M31

10x50 If you can't see it with your unaided eye, start with Mirach (Beta (β) Andromedae) at one side of the field of view and Mu (μ) Andromedae at the other. Place Mu Andromedae where Mirach was, and the elliptical Andromeda Galaxy, M31, will appear where Mu Andromedae was. Notice the brighter glow of the galaxy's nucleus and see if you can identify the two companion galaxies, M32 and M110, appearing as defocused stars. ☐ **SEEN IT**

5. The Hockey Stick

15x70 Identify the easy double star, 56 Andromedae and, rising to the right, you'll see a straight-ish chain of 6th and 7th magnitude stars, forming the Hockey Stick asterism more than 1.5° long, with 56 Andromedae at the lower end and open cluster NGC 752 as a fuzzy ball. The association is an optical illusion: at 1,300 lightyears, NGC 752 is four times more distant than 56 Andromedae. ☐ **SEEN IT**

6. The Triangulum Galaxy

15x70 This low surface brightness galaxy needs a dark sky. Return to Mirach and imagine a point that is diametrically opposite it from M31. The ghostly glow of M33, the Triangulum Galaxy, may appear only as a slight brightening of the sky, even with averted vision. It is face on to us and appears about the same size as the Moon. ☐ **SEEN IT**

☑ Tick the box when you've seen each one

PETE LAWRENCE X 3

THE SKY GUIDE CHALLENGE

How many galaxies can you spot that are bound to the Andromeda Galaxy, M31?

The Andromeda Galaxy, M31, becomes well placed in September. Good binoculars or a small telescope also reveal two satellite galaxies, M32 and M110 nearby. However, these aren't the only galaxies gravitationally bound to M31. This month's challenge is to hunt down some of the others.

There are actually quite a few, the latest count including at least 32 entries. Many of these are faint and difficult to discern but a number are within amateur range. M32 has an integrated magnitude of +9.2 and is easy to find as it lies close to the M31, situated just 23 arcminutes south of the core. M110 is of similar integrated magnitude at +9.4, but is more spread out with a lower surface brightness. It lies 37 arcminutes northeast of M31's core.

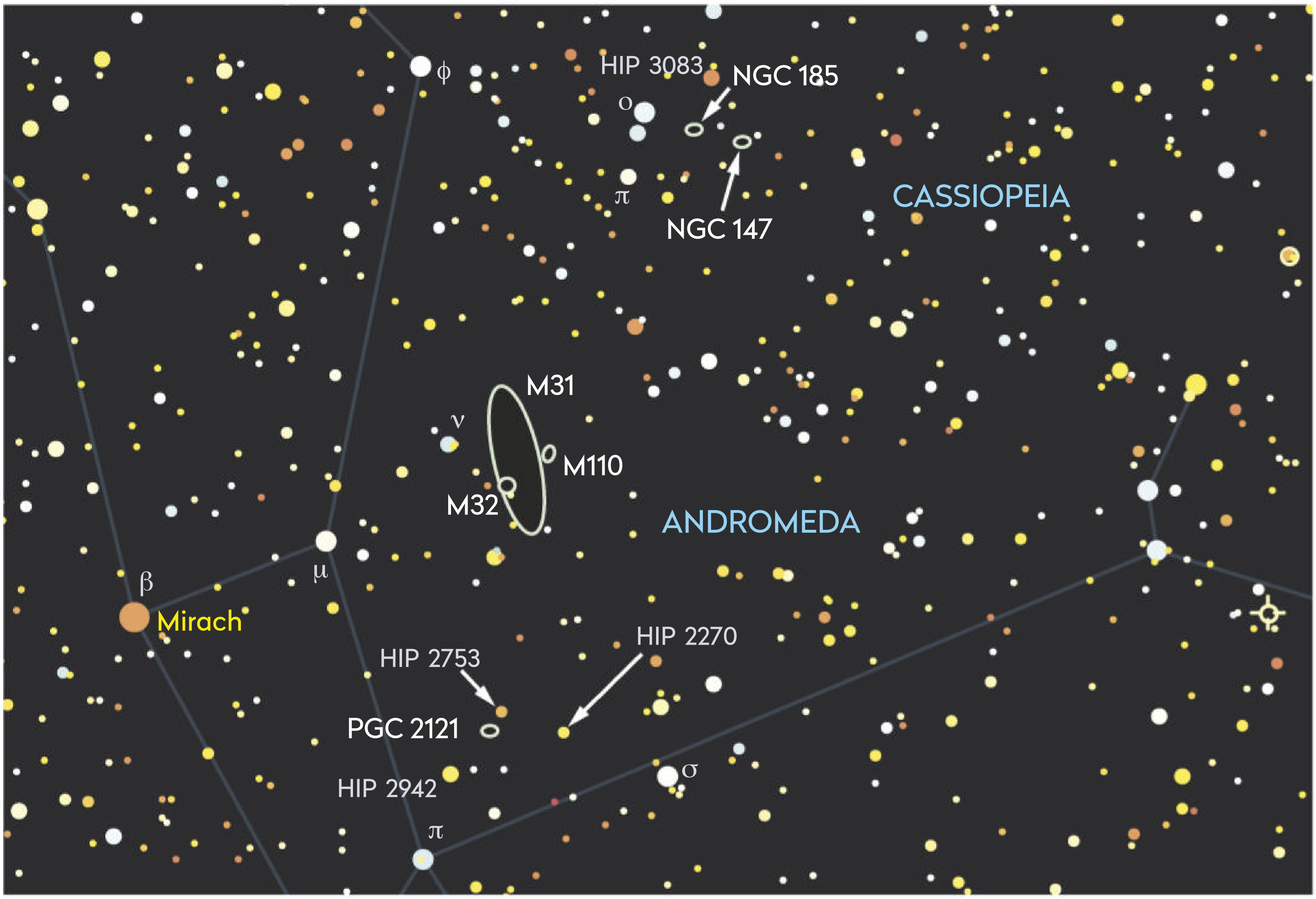
In theory, the next satellite galaxy in terms of brightness is Andromeda VIII, a dwarf spheroidal galaxy discovered in 2003. Its integrated magnitude is +9.7 but it's also large at 45.0 x 10.0 arcminutes. This spreads its light over a large area giving it a low surface brightness, explaining why it took so long to detect.

Surface brightness is also low for NGC 185 and NGC 147, both located in neighbouring Cassiopeia. With respective integrated magnitudes of +10.1 and +10.5 respectively, although their 11.7 x 10.0 and 13.2 x 7.8 arcminute sizes present dim targets, they are still well within reach of amateur equipment.

Our charts show the location of both galaxies. Both are really close to one another, just less than a degree apart. Visually, both can be seen through binoculars under dark-sky conditions but for the best views, apertures over 250mm are recommended. If you're into imaging, a wide-field shot with both galaxies in the frame would work well. Realistically, expect to record sizes roughly half those stated.

NGC 147 is the hardest. It's faint and elongated in shape. A number of faint foreground stars appear clustered over the core of the galaxy, misleading you into thinking you're seeing something brighter than it is. NGC 185's brightness is more concentrated towards its core and this makes it easier to see. Deep-sky photography can be used to reveal a dark dust feature in NGC 185, giving an appearance not dissimilar to a fainter version of M64, the Black Eye Galaxy.

If you fancy a real challenge, of the many other faint satellites of M31, Andromeda III (PGC 2121) is another low surface brightness target within amateur-imaging range. Using a star chart app, the galaxy sits 5° south-southwest of M31, one-third of the way along a line from TYC 2274-1298-1 (mag. +10.9) and TYC 2274-0735-1 (mag. +10.2). It shines at mag. +13 and is 3.0 x 4.5 arcminutes in size.



▲ **See if you can spot NGC 185 and NGC 147 north of the Andromeda Galaxy, and then the more tricky PGC 2121 to the south-southwest**

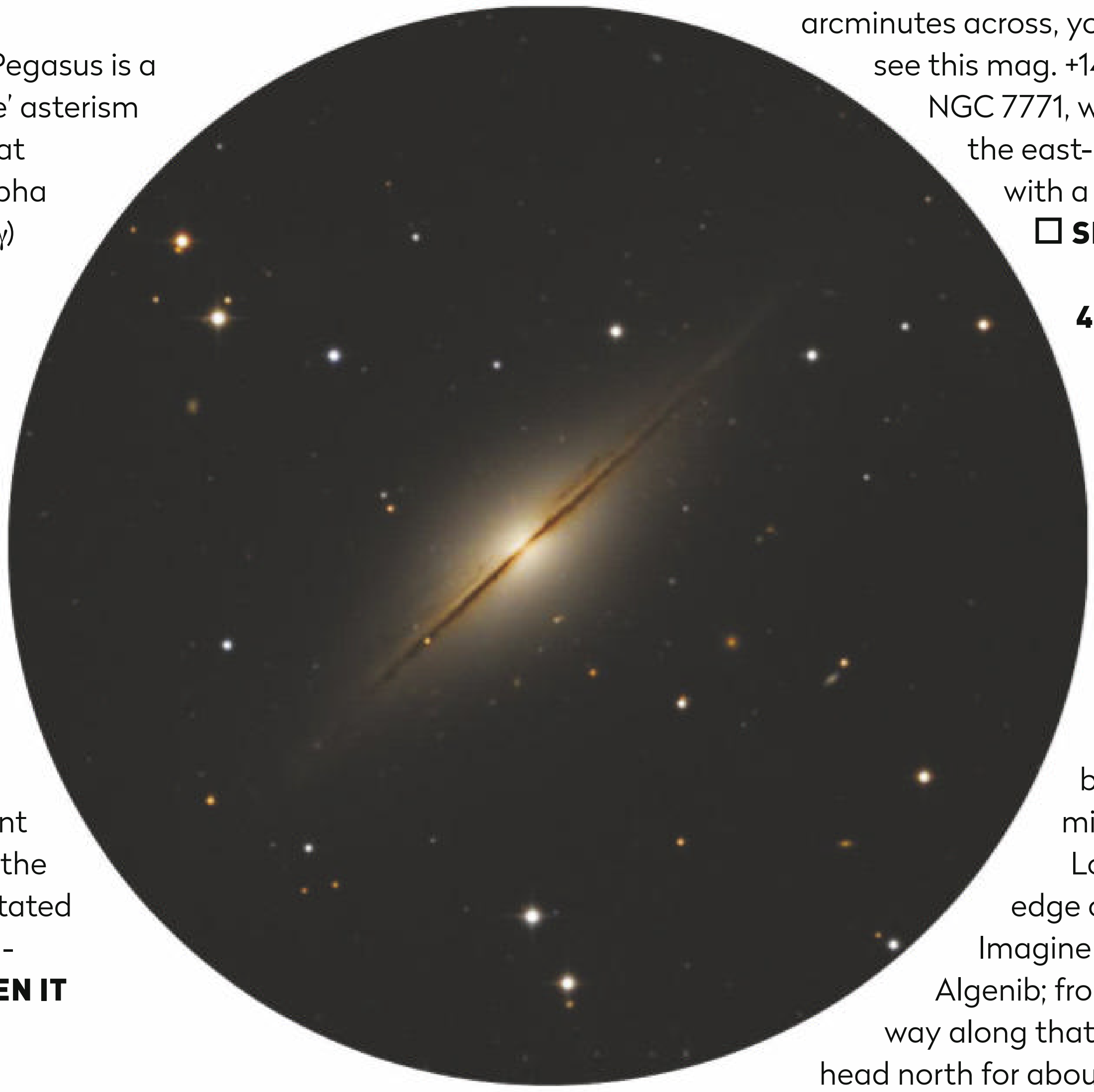
DEEP-SKY TOUR

Discover the irregular and spiral galaxies within the Great Square of Pegasus asterism

1 NGC 14

The Great Square of Pegasus is a large distorted 'square' asterism formed from Markab, Scheat and Algenib in Pegasus (Alpha (α)), Beta (β)) and Gamma (γ) Pegasi respectively) along with Alpheratz (Alpha (α) Andromedae).

We'll start with the faint but easy to locate irregular galaxy NGC 14. It has an apparent magnitude of +12.7, but is diffuse. At a distance of 47.1 million lightyears, it appears as little more than a faint smudge. It's located 1.25° northwest of Algenib and has an apparent size of 2.0 x 1.3 arcminutes, the elongated dimension orientated in a north-northeast/south-southwest direction. ☐ **SEEN IT**



▲ **Spiral galaxy NGC 7814 is 40 million lightyears away**

2 NGC 7814

Our next target sits 1.4° west-northwest of NGC 14, or if you had trouble with that galaxy, 2.6° west-northwest of Algenib. It also sits 13 arcminutes southwest of mag. +7.2 star HIP 199. NGC 7814 is a nice spiral galaxy around 40 million lightyears away. Shining with an integrated magnitude of +11.6, it's tilted to our line-of-sight to appear edge on to us: a thin light strip with a central bulge.

Smaller instruments show its elongation well, about 3 arcminutes in length oriented southeast-northwest with a 1 arcminute rough-textured core. The core appears condensed and a bit asymmetric. Long-exposure images through large scopes reveal a dust lane running the galaxy's length. ☐ **SEEN IT**

3 NGC 7769, NGC 7770 and NGC 7771

NGC 7769 is a relatively bright face-on spiral galaxy, located 1.1° north-northwest of mag. +5.0 Phi (φ) Pegasi. It has an integrated magnitude of +12.1 and appears about 1 arcminute across. A 250mm instrument reveals a small concentrated core with a faint, star-like nucleus.

Two additional galaxies occupy the field of view. The faintest by far is NGC 7770. Listed as 1.0 x 0.9 arcminutes across, you'll need a big scope to see this mag. +14.5 object. Much easier is NGC 7771, which lies 5.4 arcminutes to the east-southeast of NGC 7769, with a brightness at mag. +12.3. ☐ **SEEN IT**

4 NGC 7625

NGC 7625 is another spiral located within the Great Square's boundary. This time the orientation presents us with an almost circular object, 1.6 x 1.4 arcminutes across. It shines at an integrated magnitude of +11.9 and is believed to be around 81 million lightyears away.

Locate it via the southern edge of the Great Square. Imagine the line from Markab to Algenib; from a point a quarter of the way along that line (starting at Markab), head north for about one-eighth the length of the line (about 2°) and you'll be in the right area. A mag. +6.7 star sits 6.6 arcminutes east of the galaxy. A 250mm scope shows NGC 7625 as having a high surface brightness. ☐ **SEEN IT**

5 NGC 7741

Next, we head north to find the barred spiral galaxy NGC 7741. The easiest locator is mag. +4.9, 78 Pegasi, itself located by looking two-fifths along the northern edge of the Great Square starting at Alpheratz. Once found, drop south from the star by 3.2° to locate NGC 7741.

The galaxy has an integrated magnitude of +11.4, but its apparent size is large, at the extreme measuring around 4.0 x 2.8 arcminutes, meaning its surface brightness is low. A 250mm scope shows a 3.0 x 2.0 arcminute object, the faint glow marginally increasing in brightness towards its core. ☐ **SEEN IT**

6 NGC 1 & 2

Our final targets mark the start of the NGC catalogue. NGC 1 and 2 are two spiral galaxies appearing close to one another in the northeast corner of the Great Square. NGC 1 is an intermediate spiral. It shines with an integrated magnitude around +13.0. Its surface brightness is low, approaching 14th magnitude, but it has a bright concentrated core. The apparent diameter of NGC 1 is around 45 arcseconds.

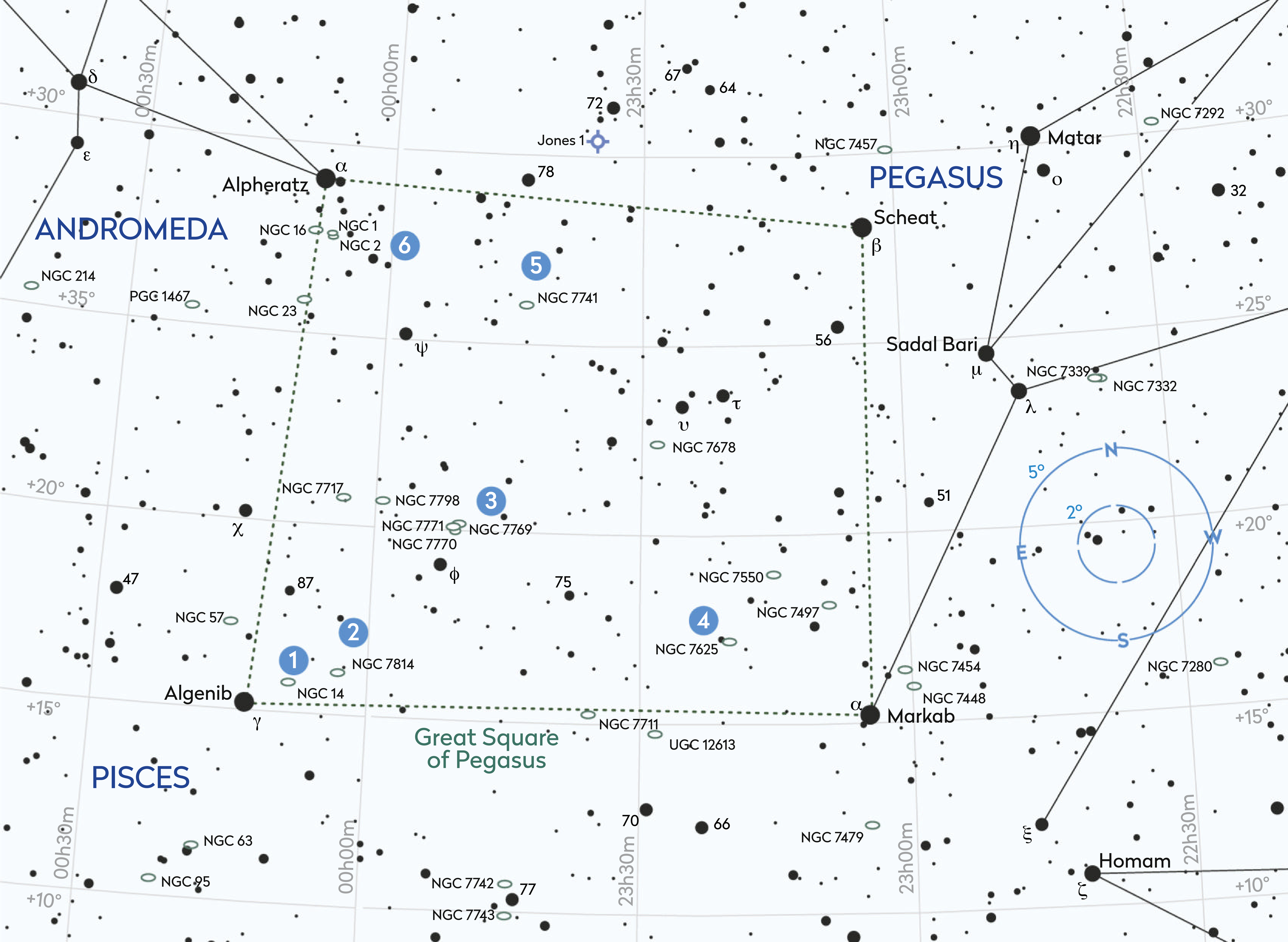
NGC 2 lies 1.8 arcminutes further to the south. This is hard to spot, its integrated brightness being around the mag. +14.5 mark. ☐ **SEEN IT**

This Deep-Sky Tour has been automated
ASCOM-enabled Go-To mounts can now take you to this month's targets at the touch of a button, with our Deep-Sky Tour file for the EQTOUR app. Find it online.

More **ONLINE**

Print out this chart and take an automated Go-To tour. See page 5 for instructions.

MICHAEL BREITE/STEFAN HEUTZ/WOLFGANG RIES/CCDGUIDE.COM, CHART BY PETE LAWRENCE



PEGASUS
ANDROMEDA
PISCES
Great Square of Pegasus
Alpheratz
Scheat
Markab
Algenib
Matar
Sadal Bari
Homam
Jones 1
NGC 7292
NGC 7457
NGC 16
NGC 1
NGC 2
NGC 214
PGC 1467
NGC 23
NGC 7741
NGC 7339
NGC 7332
NGC 7678
NGC 7717
NGC 7798
NGC 7771
NGC 7770
NGC 7769
NGC 7550
NGC 7497
NGC 57
NGC 7625
NGC 7814
NGC 14
NGC 7454
NGC 7448
NGC 7280
NGC 7711
UGC 12613
NGC 63
NGC 95
NGC 7479
NGC 7742
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00h30m
00h00m
23h30m
23h00m
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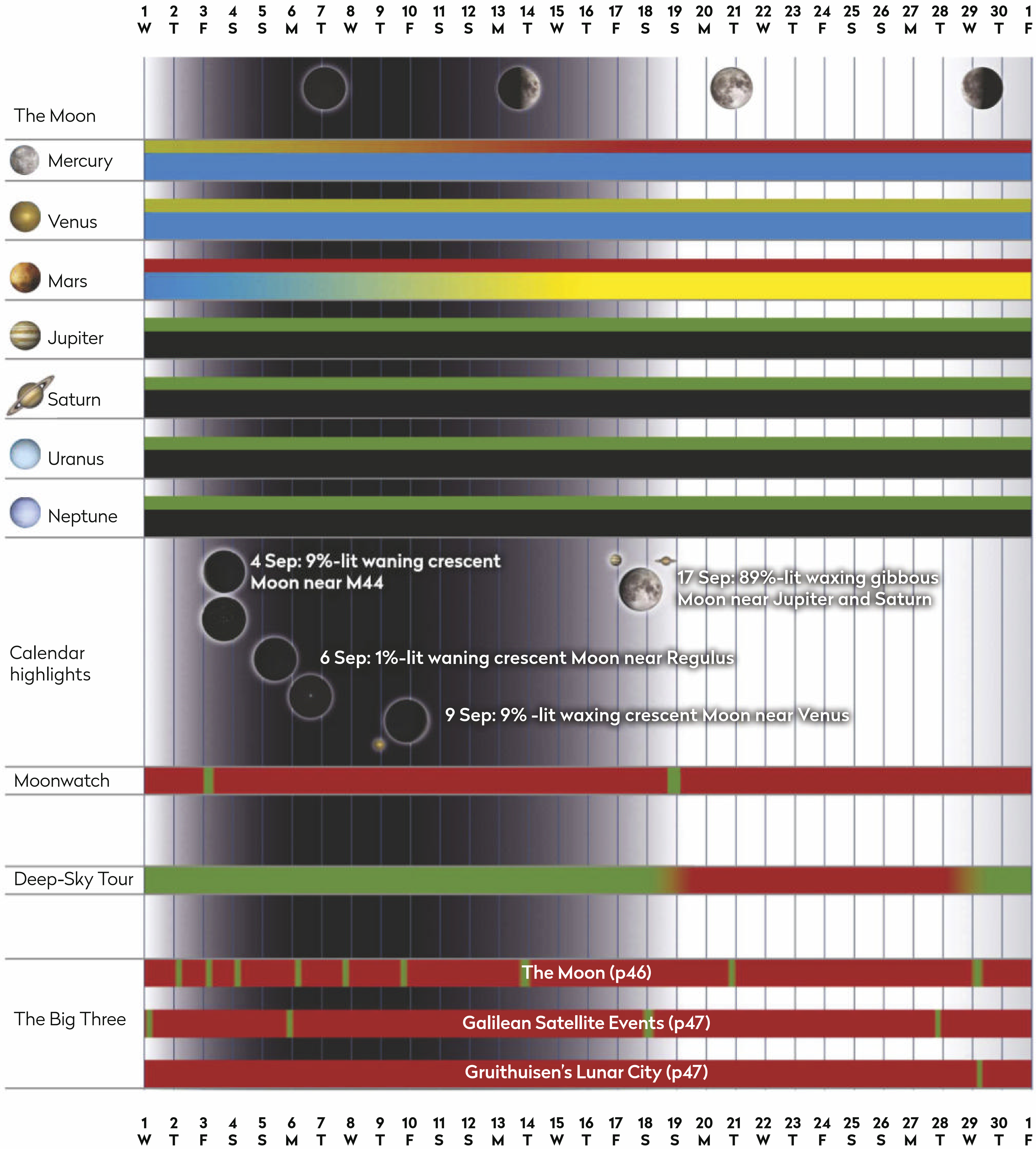
+10°
+15°
+20°
+25°
+30°
+35°

AT A GLANCE How the Sky Guide events will appear in September



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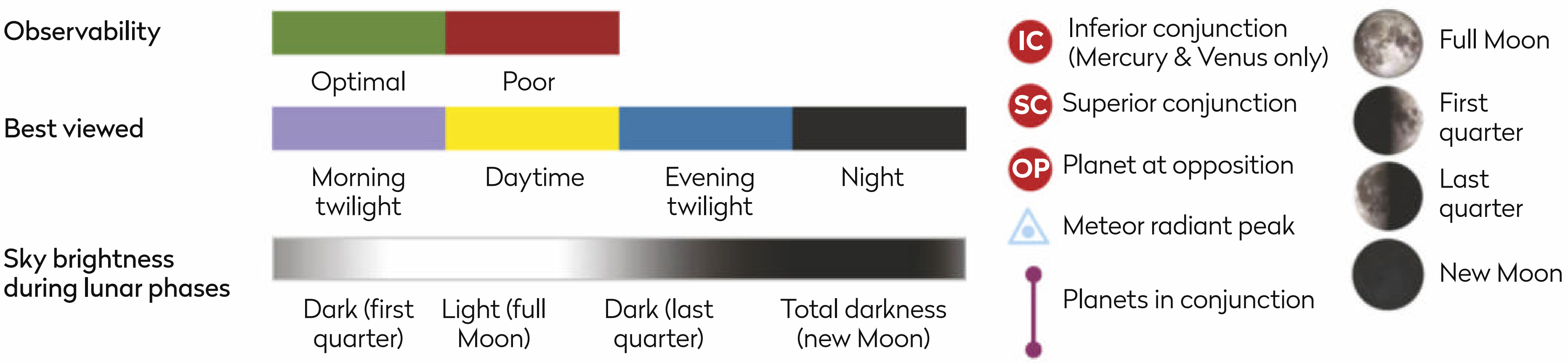


CHART BY PETE LAWRENCE

You'll love this camera to Arp 273 and back!

Apx60

The wait is over! Atik Cameras' 60-megapixel CMOS camera is now in production and we're sure you're going to love it.

The Apx60 utilises the Sony IMX455 full-frame CMOS sensor that is revolutionising amateur astronomy. This 60-megapixel sensor has low read noise, high quantum efficiency, and 16-bit analogue-to-digital conversion. It's perfect for large-format, wide-field views with outstanding detail.

The Apx60 comes complete with high-performance cooling, anti-condensation and anti-reflection optics, as well as easy sensor levelling adjustments. The camera has a 512mb memory buffer to prevent image artifacts and dropped frames. Additionally, the Apx60 is compatible with our intuitive software, and offers Atik's customary premium build quality.

You can get the Apx60 NOW!
See our website for details of our worldwide dealers.

ATIK CAMERAS

See the full Atik range at www.atik-cameras.com

WIN! To celebrate the launch of our 60-megapixel camera, we're offering you the chance to win a brand new Apx60. Head over to the Apx60 competitions page on our website, and simply enter the code **S@N21** to enter. Competition closes 31 October 2021. T&C's apply.

Google's astronomy Doodles

Ian Ridpath takes a look at the informative and amusing astronomy illustrations that have graced Google searches over the years

Anyone who has ever searched the internet will most likely have encountered a Google Doodle – a graphic or animation at the top of the Google search page. Doodles celebrate anniversaries, events and individuals, among them a fair selection of astronomers, space missions and astronomical discoveries.

Doodles were born in 1998 when Larry Page and Sergey Brin, Google's founders, modified the site's logo to include the symbol of the Burning Man festival, which they'd gone to that week. They described it as a visual 'out of office' message. New Doodles appear on an almost daily basis now, created by a dedicated team.

All past Doodles are kept in an archive at **www.google.com/doodles#archive**. Of the 4,000-plus Doodles produced to date, around 75 have astronomy connections. Here are some favourites...

◁ Einstein

Many Doodles involve a visual play on the distinctive Google logo. An amusing example is the first astronomically related Doodle, released on 14 March 2003 to commemorate Albert Einstein's birthday. Einstein's famously unruly hair adorns the first letter 'o', while the final letter 'e' has been co-opted to form part of his classic equation $E = mc^2$ (overlooking, for artistic purposes, the fact that the 'E' in the equation should be a capital).

▽ Women astronomers

Women astronomers have been celebrated in a number of Doodles, including the comet discoverer Caroline Herschel, depicted in 2016 on her 266th birthday. We see Caroline, her skirts billowing in the Slough breeze, bending down to look through a small refractor perched uneasily on a table while a meteor shower blazes through the skies above her. There are two mistakes here that any reader of this magazine should spot immediately. Firstly, in reality she didn't use a refractor, but a small reflector made for her by her brother William Herschel; and secondly, meteors aren't the same thing as comets, which was what she was famous for discovering. Incidentally, William and his son John Herschel remain 'unDoodled' so far.

A Doodle shower ▷

The Perseids have been Doodled twice, in 2009 and 2014, the latter with a mood-music soundtrack. But it's the Doodle for the Geminid meteor shower in 2018 (right) that I find most enchanting. A slideshow of seven frames traces the stream of debris left by the Geminids' parent body, the 'rock comet' Phaethon, from its orbit around the Sun to its annual encounter with Earth. The stand-out feature is the three-dimensional transitions against a starry background as the slides advance.

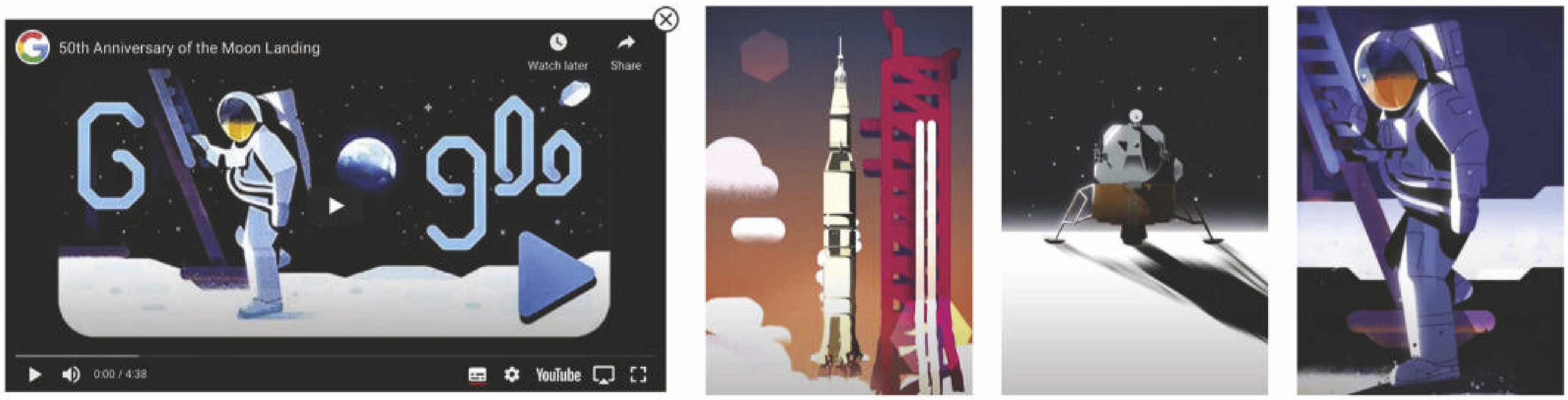
ALL PICTURES: © GOOGLE

Doodling space ▷

Spacecraft and space missions feature prominently as Doodles, among them the 50th anniversary of Sputnik 1 (2007), the 20th anniversary of the Hubble Space Telescope (2010) and New Horizons' Pluto flyby (2015). Visually, the most entertaining space Doodle to date was of the Cassini spacecraft diving between Saturn and its rings in April 2017 (right). Artist Nate Swinehart depicted the probe as an interplanetary paparazzo snapping a series of shots before turning the camera on itself for a sneaky selfie.

▽ Apollo 11

Apollo 11's lunar landing has been Doodled three times, in 2005, 2009 and on its 50th anniversary in July 2019. For the 50th anniversary Google gave it the full Hollywood treatment with a four-and-a half-minute video produced by a team of artists, researchers and audiovisual technicians, and a narration by Apollo 11 astronaut Michael Collins.



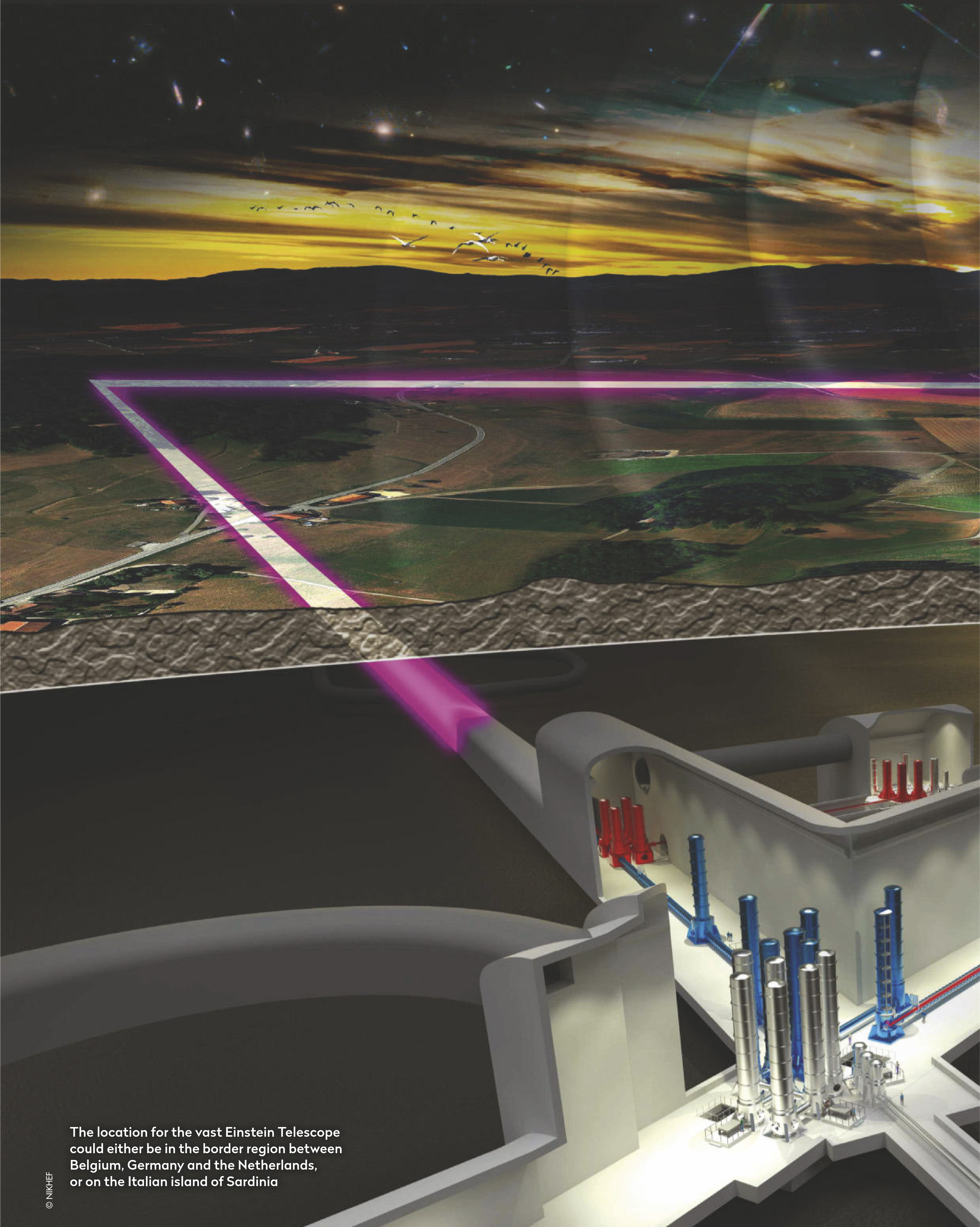
▷ Into the black hole

On 10 April 2019 astronomers released the first image of a black hole taken by the Event Horizon Telescope. Artist Nate Swinehart (by now our favourite astro-Doodler) was already sketching ideas on his way to work that morning, and later that same day his animated Doodle went live on Google's home page. In the Doodle, the black hole first sucks in stars, then the logo and finally the photograph itself, leaving inky blackness. It's a tremendous tribute to the imagination and skill of the Doodlers.

▽ The Great Conjunction

The most recent astro-Doodle celebrated the Great Conjunction between Jupiter and Saturn last December, a once-in-800-years event that coincided with the winter solstice. In the animation, as Saturn swings past Jupiter it stops to doff its rings and high-five the giant planet, while Earth, below, jumps for joy. The Doodle came in two versions, one for Northern Hemisphere viewers in which the Google logo was layered with snow, and one for the Southern Hemisphere without snow.

Ian Ridpath is a veteran populariser of astronomy. His books include the *Collins Stars and Planets Guide*, *Collins Gem Stars* and *The Monthly Sky Guide*, all in print for over 30 years. Find him at **www.ianridpath.com**



The location for the vast Einstein Telescope could either be in the border region between Belgium, Germany and the Netherlands, or on the Italian island of Sardinia

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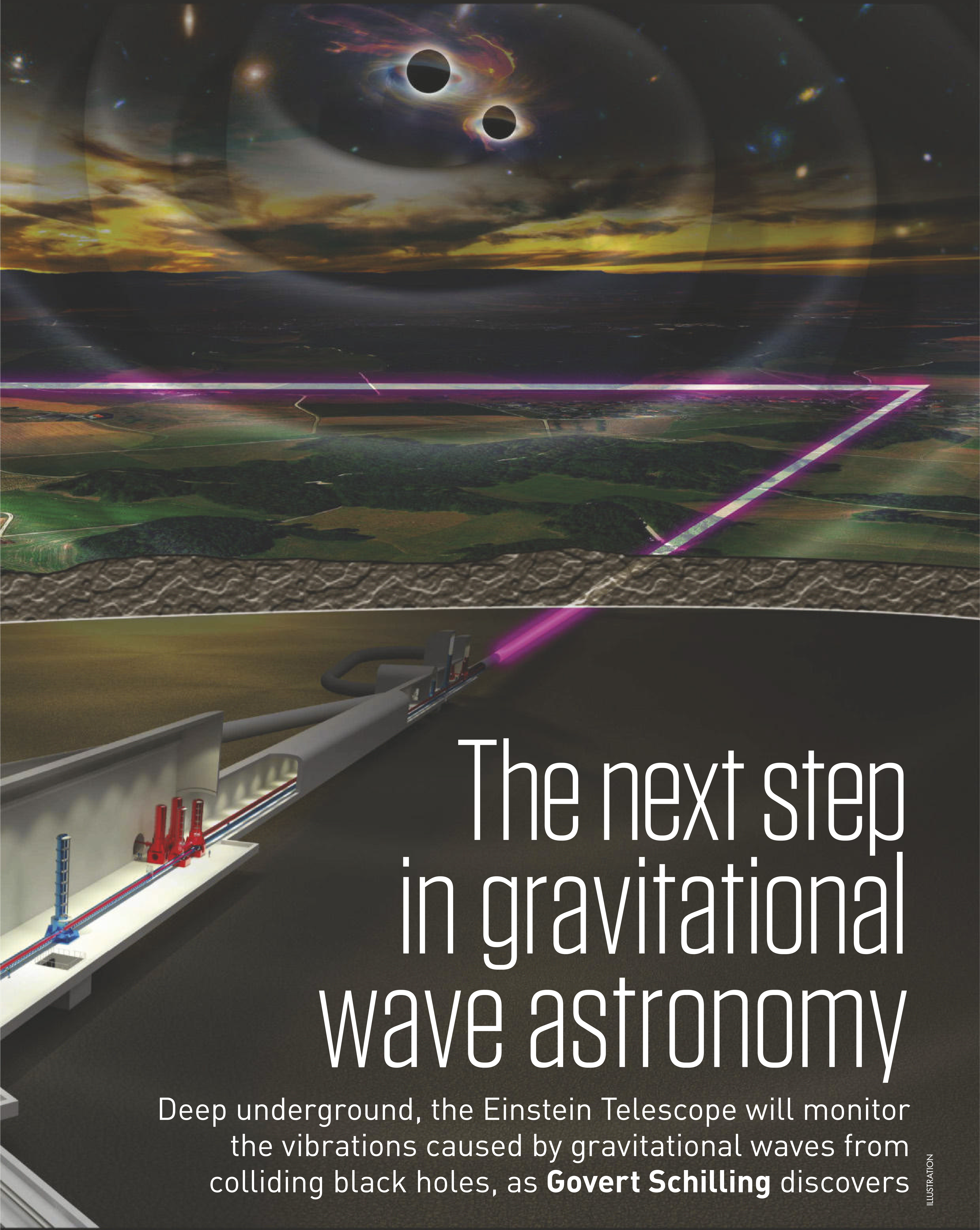
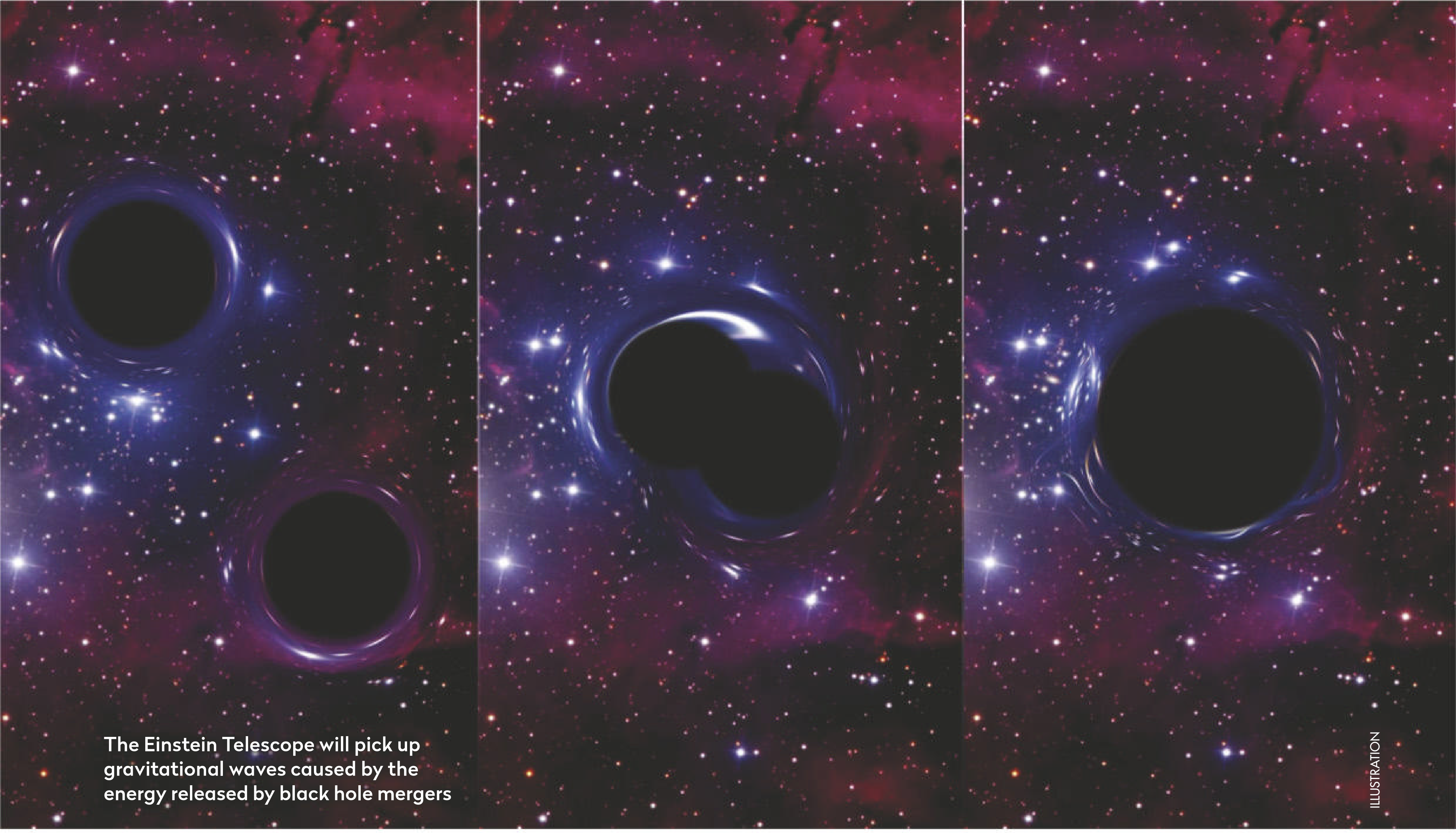


The next step in gravitational wave astronomy

Deep underground, the Einstein Telescope will monitor the vibrations caused by gravitational waves from colliding black holes, as **Govert Schilling** discovers

ILLUSTRATION



The Einstein Telescope will pick up gravitational waves caused by the energy released by black hole mergers

ILLUSTRATION

The most sensitive instrument in the history of astronomy is going to be built in deep underground caverns and tunnels, a few hundred metres beneath Earth's surface. It may sound crazy, but it's true. The Einstein Telescope (ET) isn't going to collect light photons and won't provide us with stunning images of nebulae and galaxies. Instead, the almost €2bn–facility will register gravitational waves, the infinitesimal ripples in spacetime that propagate through the Universe at the speed of light as a result of the collisions and mergers of ultra-compact neutron stars and gluttonous black holes.

The telescope will form a giant equilateral triangle, measuring 10km on each side. Powerful beams of laser light will travel up and down these arms, bouncing off mirrors to gauge the length of the arms to see if they change by even a fraction the width of an atomic nucleus. When such a change does occur, it could mean a gravitational wave has passed through, briefly warping the space around the detector. "Our target is to detect colliding black holes throughout the whole observable Universe," says Michele Punturo, co-chair of the international ET steering committee.

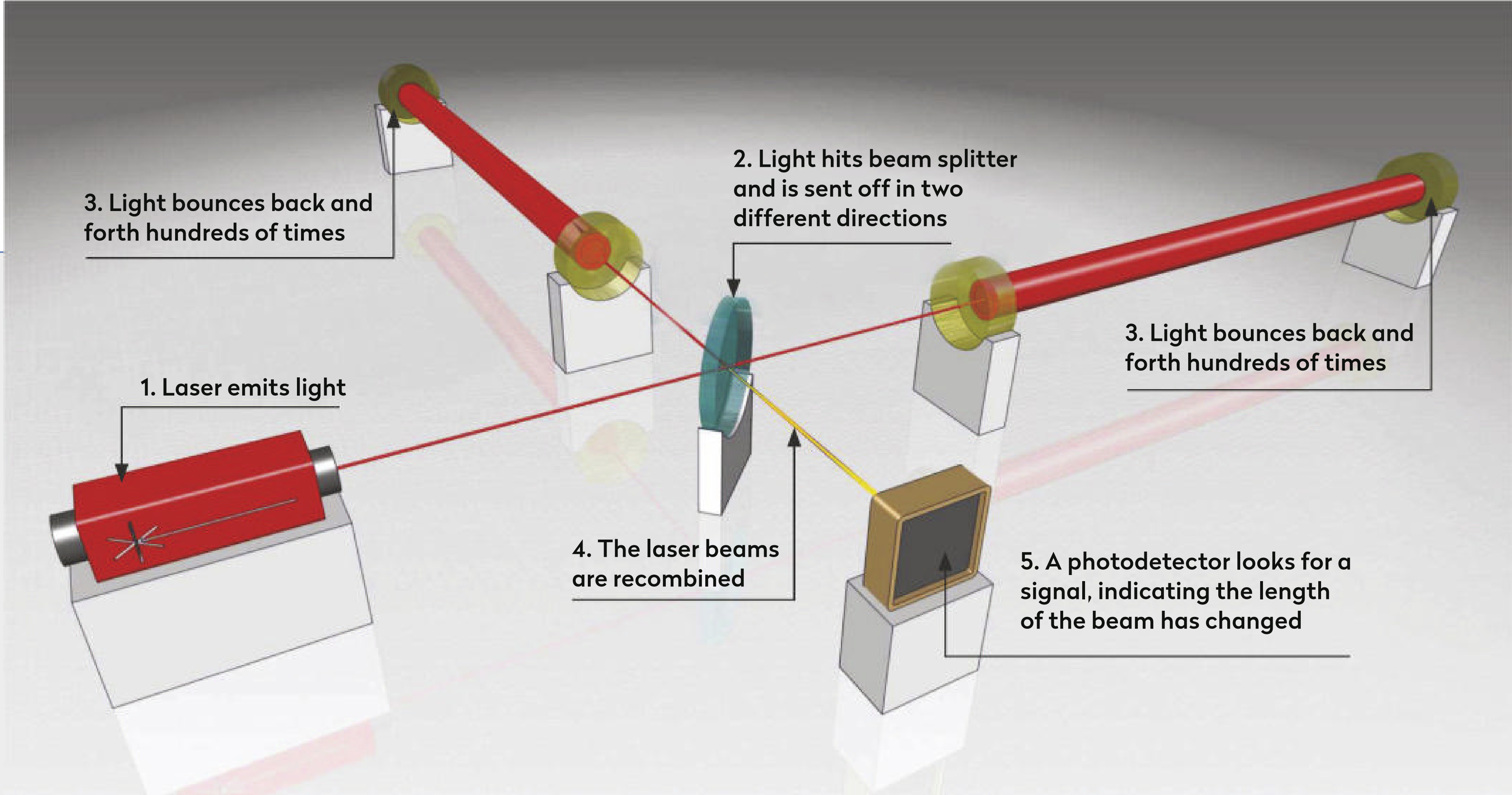
Gravitational waves were first described over a century ago by Albert Einstein. His general theory of relativity implied that spacetime could bend, warp, expand or contract, like a four-dimensional rubber sheet. Einstein also predicted that accelerating masses create tiny undulations in the very fabric of spacetime, alternately stretching and compressing everything on their paths. However, even the largest masses and the strongest accelerations would produce gravitational waves with amplitudes much smaller than an atomic nucleus. Einstein was convinced they would never be detected.

"Our target is to detect colliding black holes throughout the whole observable Universe." – Michele Punturo

Sixty years after his death, in 2015, Einstein was proven right on the existence of gravitational waves, but wrong on their non-detectability. Indeed, the two highly sensitive detectors of the Laser Interferometer Gravitational-Wave Observatory (LIGO) registered the spacetime ripples of two colliding black holes at a distance of 1.3 billion lightyears. Since that first discovery, both the US-based LIGO and the European Virgo detector in Italy have observed dozens of events, including tell-tale signals from colliding neutron stars, smash-ups of black holes and neutron stars, and black holes with unexpected masses – maybe a result of earlier mergers.

"Being able to learn more about these fascinating objects is just incredible," says theoretical astrophysicist Samaya Nissanke of the University of Amsterdam. "The observations have had an enormous impact on a wide variety of scientific fields, including astronomy, physics, cosmology and general relativity. And what strikes me most is how fast we've grown completely used to actually observing black hole mergers. It's amazing."

BRIGHTSTARS/ISTOCK/GETTY IMAGES X 3, VIRGO COLLABORATION, SOARES-SANTOS ET AL AND DES COLLABORATION



How does an interferometer work?

Merging light creates an 'interference' pattern, which can be analysed

Gravitational waves are detected with sensitive interferometers. A coherent laser beam – meaning that the crests and troughs of all light waves are in sync – is split in two by a beam splitter. Half of the laser light passes right through this semi-permeable mirror, while the other half is reflected at right angles. Next, both laser beams are reflected hundreds of times between two mirrors (known as test masses) at the near and far ends of a vast kilometres-long vacuum tunnel.

The beams are then brought back together again going towards a photodetector. However, they are normally arranged such that the troughs of one light wave perfectly meet the crests of another, cancelling out the signal.

If gravitational waves from space sweep over Earth, the lengths of the two detector arms are subject to periodic variations. Depending on the direction of arrival of these waves, variations in one arm won't match those in the second. As a result, the combined laser waves no longer cancel each other out, and the detector will register a rapid flickering signal.

▲ **Composite images of GW170817 – a gravitational wave event caused by the merger of a black hole and neutron star – as captured by DECam, the Dark Energy Survey Camera at Cerro Tololo Inter-American Observatory (CTIO)**

So far, only one gravitational-wave event (known as GW170817, due to the merger of a black hole and a neutron star) has also been observed by regular telescopes, but Nissanke, who is an expert in this new field of multi-messenger astronomy – meaning she studies the Universe using methods other than just electromagnetic radiation – isn't concerned about the lack of more detections with electromagnetic counterparts. "We were lucky in the case of GW170817," she says. "It's not easy, but soon enough, we'll be getting more sensitive detectors, better 'sky localisations', and more powerful sky surveys. It will happen again."

Nissanke looks forward to the Einstein Telescope, which will be much more sensitive than either LIGO or Virgo. Reaching out to distances 10 times as large, the instrument will yield a thousand-fold increase in the number of gravitational-wave events, as volume goes up in proportion to distance cubed. "It's phenomenal," she says. "The Einstein Telescope will be able to detect many thousands of events per year."

Going underground

This will only be possible through a whole set of different improvements, explains Sheila Rowan, director of the Institute for Gravitational Research at the University of Glasgow. "The instrument will be built underground to diminish seismic noise," she says. "Some of the core components of the detector will be cooled to 10°C above absolute zero. Because of these low temperatures, the mirrors need to be made out of ultra-pure crystalline silicon instead of more regular glass or quartz. We're also reaching out to lower-frequency waves," which increases the instrument's ability to detect in-spiralling binary black holes at an earlier stage. Last but not least, each of the three arms of the Einstein Telescope will be 10km long, greatly increasing the sensitivity compared to LIGO's arm length of just 4km.

Each LIGO and Virgo detector is fitted with just one interferometer, located where the two arms of the L-shaped detector meet. But the triangle-shaped Einstein Telescope can hold an interferometer ▸

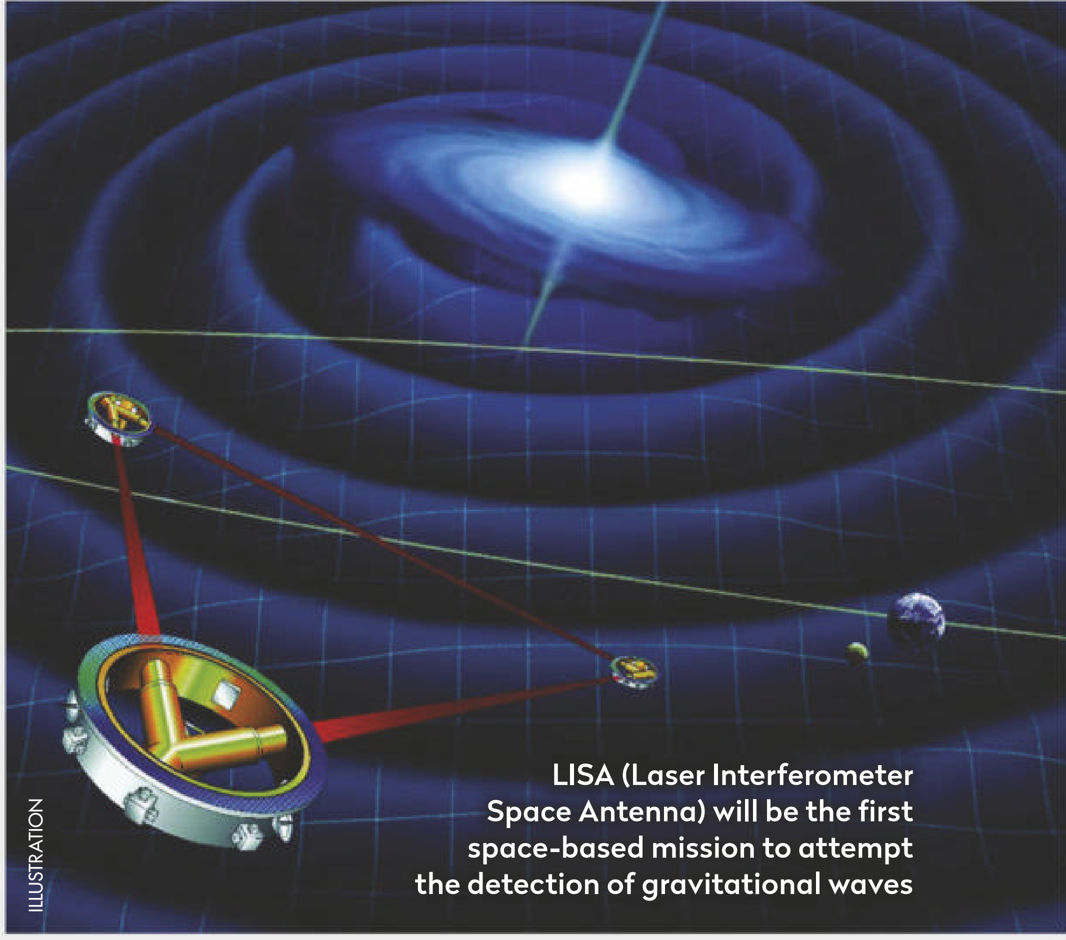
A multitude of gravitational wave detectors

A roundup of the interferometer projects around the world

The US Laser Interferometer Gravitational-wave Observatory (LIGO) consists of two identical detection facilities with 4km-long arms: one in Hanford, Washington, and the other in Livingston, Louisiana. The slightly smaller European Virgo detector, with 3km-arms, is located near Pisa, Italy. In early 2020, the underground Japanese Kamioka Gravitational-wave detector (KAGRA) came online, also with 3km arms.

Apart from LIGO, Virgo and KAGRA, a smaller experiment known as GEO600 is located near Hanover, Germany, but this facility is mainly used to test and qualify novel detection technologies – it is too small to detect all but the most powerful gravitational waves. Meanwhile, US and Indian physicists are teaming up to build LIGO India, working with spare parts from LIGO. It is expected to be completed later this decade.

In 2016, using their LISA Pathfinder space probe, the European Space Agency (ESA) successfully demonstrated the necessary technologies for its future Laser Interferometer Space Antenna (LISA), due to be launched in the 2030s. LISA will consist of three free-flying spacecraft, millions of kilometres apart; they are the vertices of a huge triangular gravitational-wave detector that has a similar design to the planned Einstein Telescope, but operating at much lower frequencies. Japan and China are also preparing space-based detectors, known as DECi-hertz Interferometer Gravitational-wave Observatory (DECIGO) and TianQin, respectively.



LISA (Laser Interferometer Space Antenna) will be the first space-based mission to attempt the detection of gravitational waves

▸ at each of the three vertices. In fact, it will hold two interferometers at each vertex, looking for gravitational waves of lower and higher frequencies, as the lower the frequency the larger the mass of the source. The Einstein Telescope's multi-interferometer setup will also make it possible to study the polarisation of the spacetime ripples, providing useful information about how the black holes were spinning as they collided.

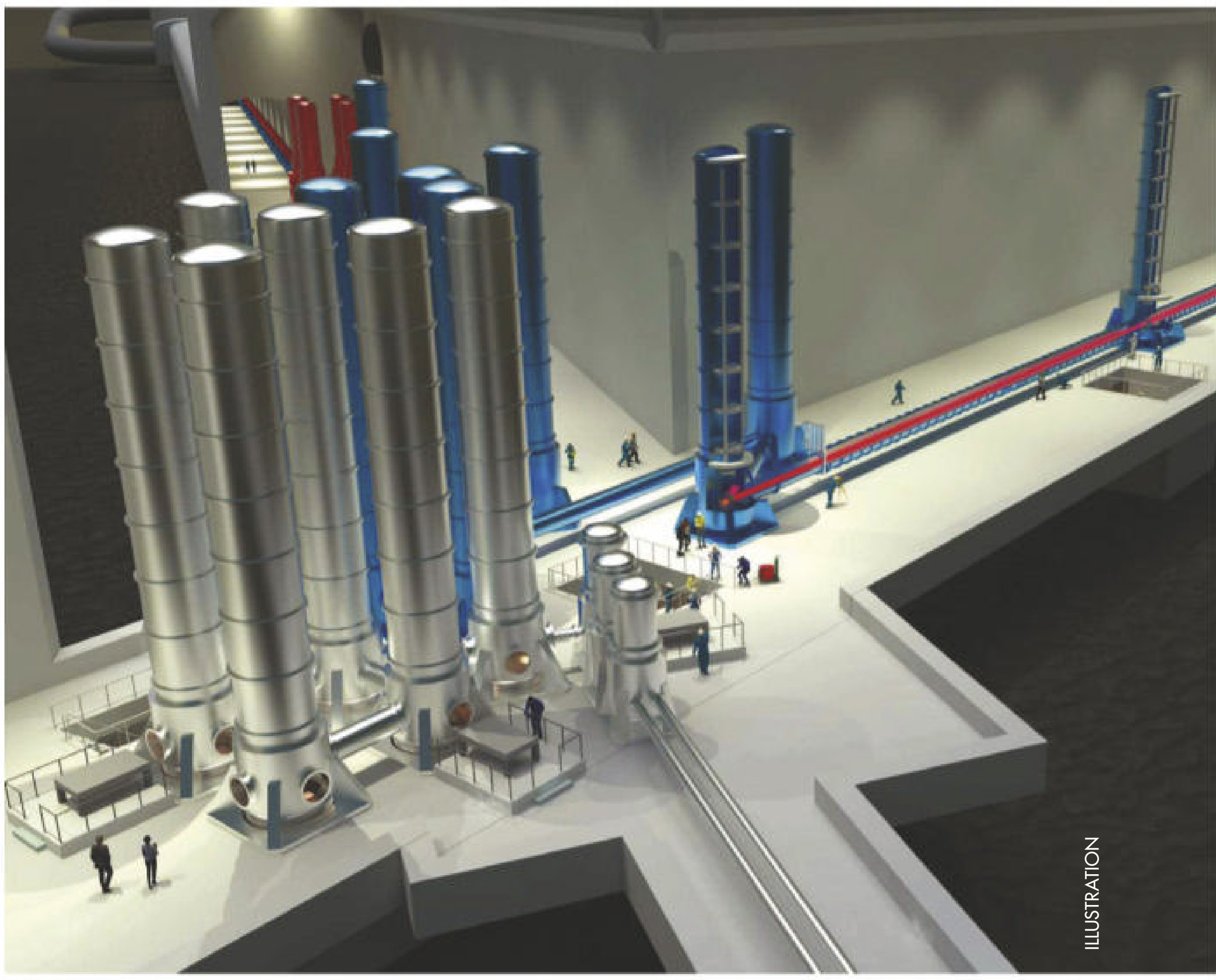
Partners in science

Punturo notes that the current design of the Einstein Telescope is still rather preliminary. It could change in the future, perhaps in response to the plans for an American counterpart, known as the Cosmic Explorer, which is still at an earlier stage of development. "No, we don't call it a competitor," he says. "We are partners in science, and the best science will be achieved by mutual cooperation between various facilities." The same is already very much true for LIGO and Virgo (and other gravitational-wave detectors).

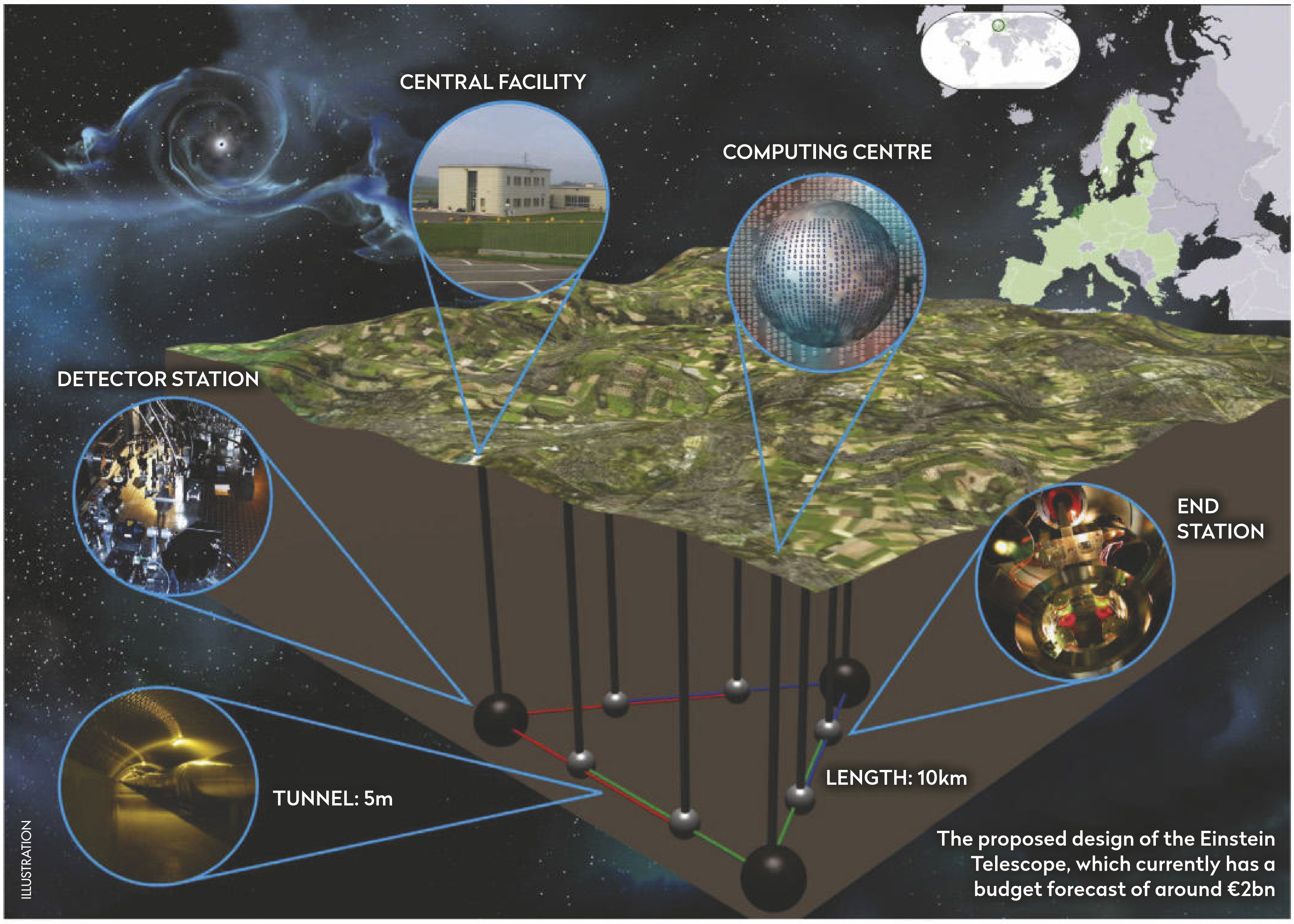
There's no doubt, however, that many new technologies will have to be incorporated in the Einstein Telescope. That's why scientists are constructing the €15m ET Pathfinder – a testbed for cryogenic components, silicon mirrors, novel suspension mechanisms and new types of lasers. The scale the detectors will be working on are so small that quantum mechanics will start having an effect, so they also need to trial smart measurement techniques that will diminish the effect of the Heisenberg uncertainty principle (which concerns the difficulty of measuring the position and momentum of a particle at the same time). "We expect ET Pathfinder to be up and running in late 2022," says Stefan Hild of Maastricht University in the Netherlands, the leader of the construction effort.

ET Pathfinder is being built in a former newspaper printing plant that has been converted into a high-quality 1,000-square-metre clean room with a 50cm-thick floor supported by 170 concrete piles measuring 6m-long and 30cm in diameter. With arm lengths of just 10m or so, ET Pathfinder won't be able to actually detect gravitational waves, but most components of the testbed facility are fully functional. "Over the next months, we will be building quite a lot of things," says Hild, who received a

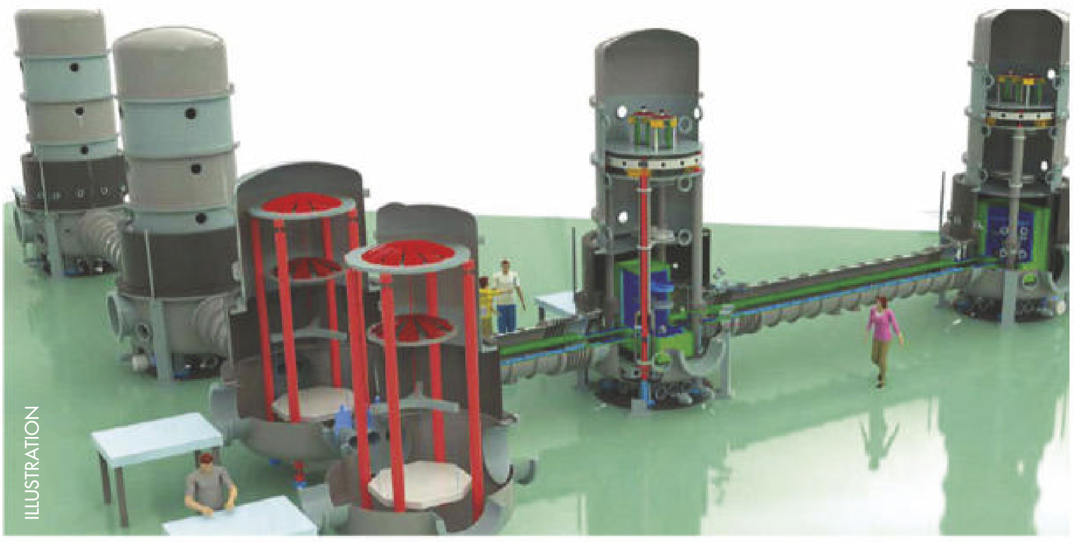
▼ An artist's impression of the inside of the Einstein Telescope gives a sense of its colossal scale



ESA, © NIKHEF X 2, © NIKHEF/KEES HUYSER,



The proposed design of the Einstein Telescope, which currently has a budget forecast of around €2bn



▲ ESA's ET Pathfinder facility in Maastricht will be a prototype for the Einstein Telescope


Govert Schilling is the author of *Ripples in Spacetime* (Harvard University Press, 2017)

European Research Council Advanced Grant of over €2m for developing new detection methods.

Finding a location

Maastricht, in the Netherlands, is also close to one of the two candidate locations for the full-scale Einstein Telescope: the underground facility could possibly be built beneath the tripoint of the Netherlands, Belgium and Germany. The other candidate site is located in the northeast of the Italian island of Sardinia. A final decision is not expected before 2024 or 2025. "The term 'best place' is a very complex one," explains Punturo. "It involves not only science, technology, and geology, but also politics and logistics."

Both sites are known for their low level of seismicity (even minute tremors could disturb the measurements), but Sardinia has a low population density. "Humans are noisy," says Punturo.

This summer, the European Strategy Forum on Research Infrastructures (ESFRI) included the Einstein Telescope in the plans of its 2021 Roadmap, underscoring the importance of the new facility for European science. After the site has been selected and the final design has been approved, construction of the Einstein Telescope would commence in 2026. According to Punturo, the first preliminary measurements could be made in the early 2030s, while the start of full operations is anticipated in 2035. "It will be a precision machine for black hole and neutron star mergers that are relatively nearby," says Punturo, "and a discovery machine for the distant and early Universe. We may even detect gravitational waves from primordial black hole collisions that happened during the cosmic Dark Ages, before the formation of the very first stars and galaxies."

In 2034, the European Space Agency also plans to launch its Laser Interferometer Space Antenna (LISA), a space-based gravitational wave detector (see box, opposite). LISA operates at a much lower frequency, enabling the detection of merging supermassive black holes in the cores of distant galaxies. Indeed, the two facilities will be very complementary in opening up a new window on the Universe. "Together, they will hopefully find a lot of missing parts of the giant cosmic jigsaw puzzle," says Nissanke. "It's just mind-blowing to imagine how astronomy will look 20 years from now."

STOCKTREK IMAGES, INC./ALAMY STOCK PHOTO

◄ **Algol, the famous variable star in the constellation of Perseus, takes its name from the Arabic word meaning 'head of the demon'**

Late summer VARIABLES

Observing variable stars is a great way for amateur astronomers to aid professional research. **Paul G Abel** is your guide to making accurate observations

A casual look at the night sky gives the impression that the stars are constant and unchanging. While it's true that many stars remain fairly constant over the course of a human lifetime, there's a large number of stars that change quite rapidly, sometimes in a matter of hours.

The ancient Egyptians knew that the star Algol (Beta (β) Persei) in Perseus changed in brightness, but it wasn't until 1638 when Johannes Holwarda discovered that the apparent magnitude of the red giant star Mira (Omicron (ο) Ceti) in the constellation of Cetus, the Whale varied over a period of about 11 months. Eventually, other stars with similar behaviour were discovered and, before long, a new area of astronomy arrived: the study of variable stars.

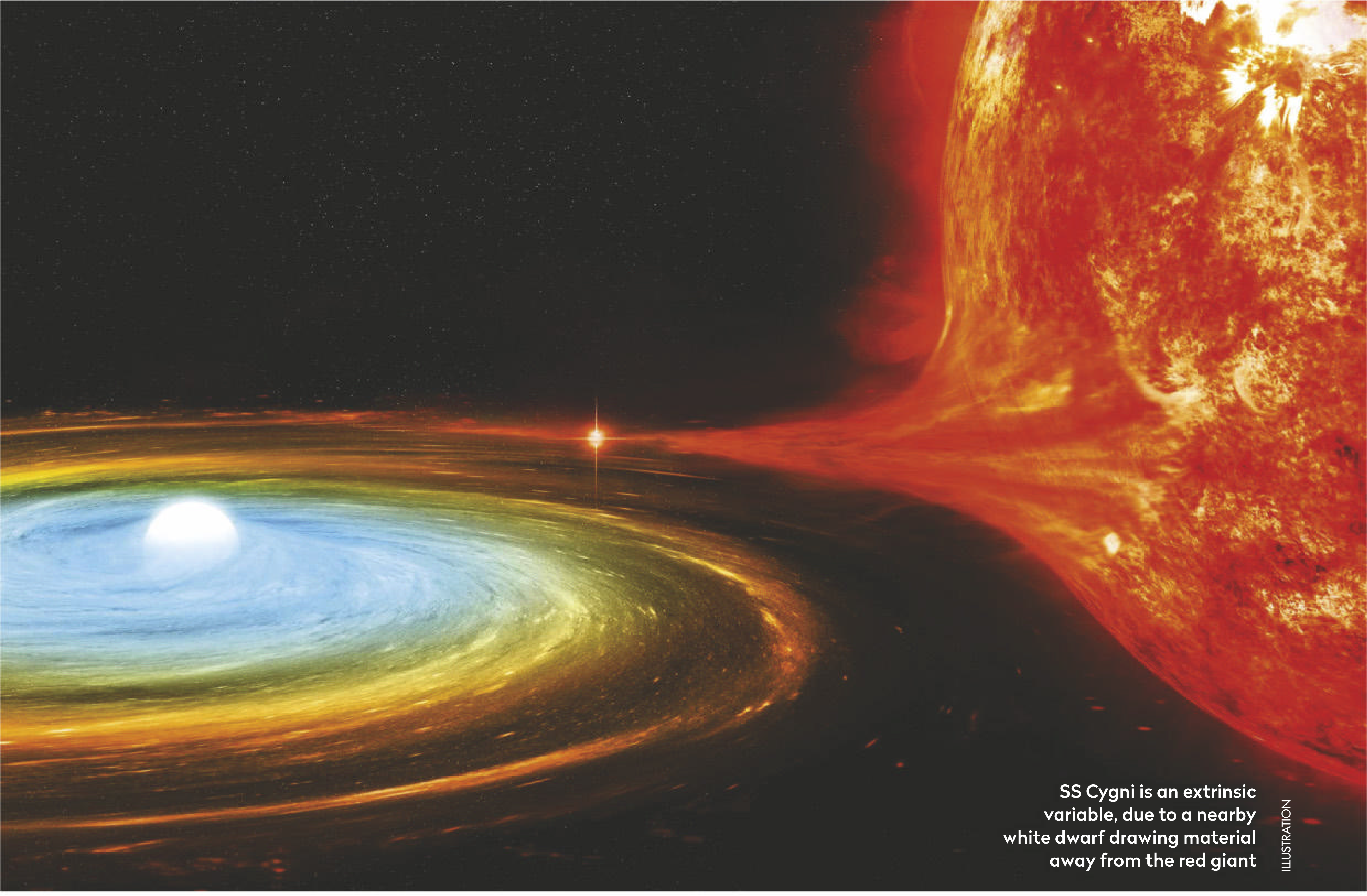
Today, variable stars play an important role in stellar astrophysics – they provide an essential laboratory in which we can test our models of stellar evolution, from bloated red giants at the end of their lives to binary stars caught in fatal gravitational ballets. Nevertheless, variable star observing is straightforward and surprisingly rewarding. It requires little more than binoculars or a small telescope, some charts and a notebook.

But why do stars vary? Fundamentally, variable stars can be broken down into two categories: intrinsic variables and extrinsic variables. Intrinsic variables are stars whose changes in magnitude are caused by physical processes within the star itself. For example, many red giants (such as Betelgeuse (Alpha (α) Orionis) or Mira) shrink and expand over a period of months – as the surface of the star expands, they become fainter; when it contracts it becomes brighter.

Eruptive variables, another example, are the result of violent changes on the surface of the star: large flare activity, for instance, can cause a star to brighten by six magnitudes. More dramatic examples include the novae and supernovae.

Outside influences

Extrinsic variables vary due to physical interactions with a nearby companion star. For example, the red giant star SS Cygni has a white dwarf companion that pulls material off the main star. This material forms an accretion disc and over time, instabilities in the disc change its viscosity, which alters the temperature and allows more material to be compacted into the disc. The end result is that the accretion disc can become very bright – it's capable of going from mag. +12.0 to mag. +8.0 in a just few days. This system is an example of a dwarf nova (quite different from a supernova, which is a supermassive star's final moments). ►



SS Cygni is an extrinsic variable, due to a nearby white dwarf drawing material away from the red giant

▸ In contrast, Algol varies in brightness due to its companion passing in front of and behind the star, which makes it an eclipsing binary system.

Getting started

When setting out to observe variable stars, the first thing you need to do is to choose some. It's a good idea to start with some variables that are easy to locate – the five variables listed on page 71 and 72 are good examples. Some need to be observed more frequently than others – pulsating Mira-type stars should only be observed once a week (as their changes are slow), while eruptive or dwarf novae can be observed on any clear night.

Variable star observing is ideal for observers with binoculars or small telescopes. In fact, you shouldn't use anything larger than a 4-inch (102mm) telescope for objects brighter than the 8th magnitude. Also be careful of bias; red giants can appear brighter than they actually are.

To begin your observations you'll need to print off a suitable variable star chart (see 'Equipment and resources' on page 73). Seeing conditions aren't too important for variable stars, but you'll want the sky to be free of haze and to avoid observing in strong moonlight. It's a good idea to record your observations in a logbook – record the date, time (in UT – Universal Time), your magnitude estimate and the chart sequence. You should also record the size and type of telescope used.

Once you have the variable star in the field of your telescope or binoculars, you'll need to estimate its brightness. Don't rush this – it's really important that you identify the variable star in the field, so spend time checking that the stars in the field of view match up with those on your chart. It's probably best to use a low-power eyepiece to begin with – this should allow you to match the stars you can see with those on your chart.

When you've located and confirmed your variable, find a suitable comparison star (ideally of similar brightness) and record how much brighter or fainter the variable is compared to it. The Pogson step method is good way to do this. You estimate the magnitude of a variable star with the help of a comparison star, using steps of 0.1 of a magnitude. ▸

▼ Record your observations of the variable stars you observe in a logbook – this log is of SS Cygni

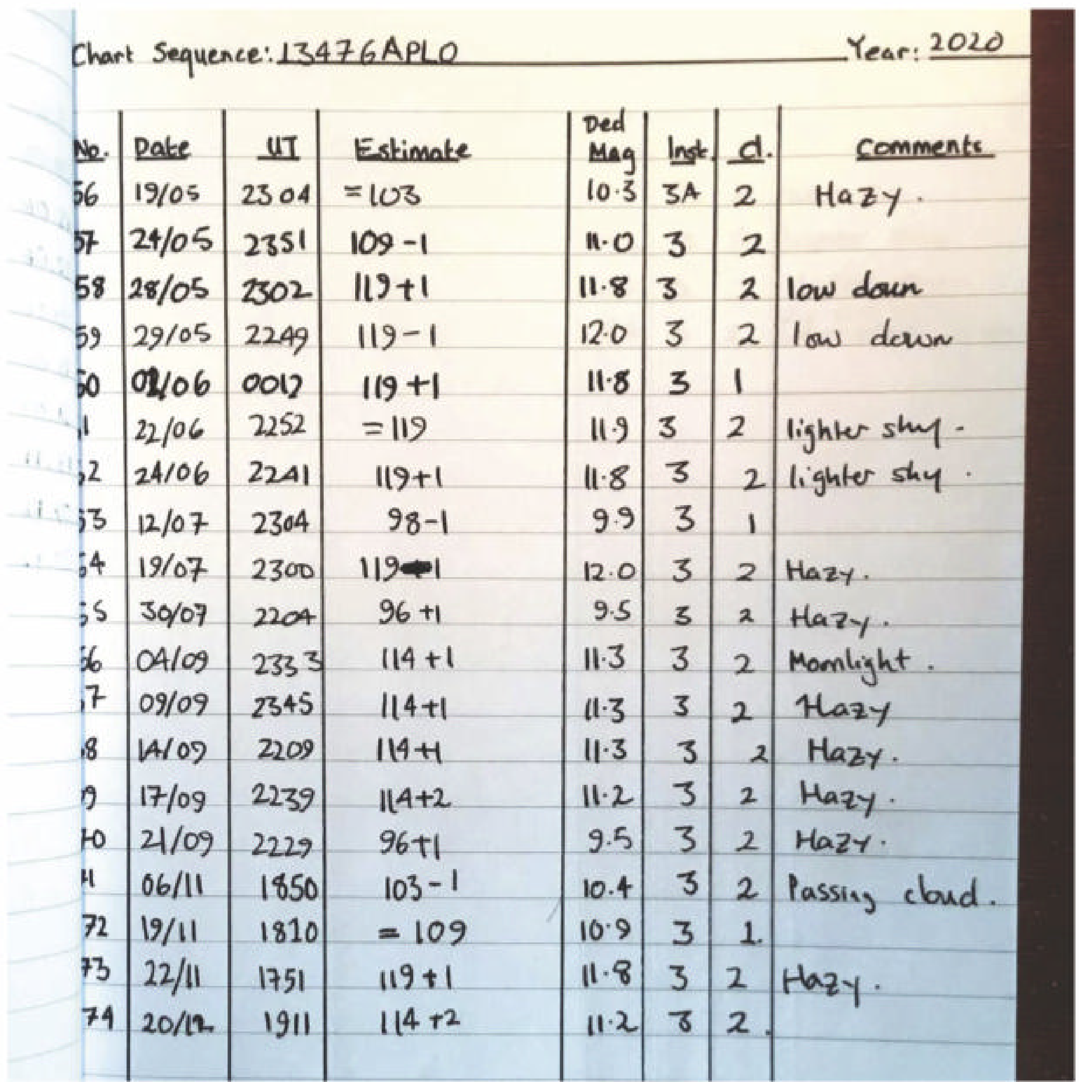


Chart Sequence: 13476APLO Year: 2020

No.	Date	UT	Estimate	Ded Mag	Inst.	d.	Comments
56	19/05	2304	=103	10.3	3A	2	Hazy.
57	24/05	2351	109 -1	11.0	3	2	
58	28/05	2302	119+1	11.8	3	2	low down
59	29/05	2249	119-1	12.0	3	2	low down
60	02/06	0012	119 +1	11.8	3	1	
61	22/06	2252	=119	11.9	3	2	lighter sky.
62	24/06	2241	119+1	11.8	3	2	lighter sky.
63	12/07	2304	98-1	9.9	3	1	
64	19/07	2300	119[illegible]1	12.0	3	2	Hazy.
65	30/07	2204	96 +1	9.5	3	2	Hazy.
66	04/09	2333	114 +1	11.3	3	2	Moonlight.
67	09/09	2345	114+1	11.3	3	2	Hazy
68	14/09	2209	114+1	11.3	3	2	Hazy.
69	17/09	2239	114+2	11.2	3	2	Hazy.
70	21/09	2229	96+1	9.5	3	2	Hazy.
71	06/11	1850	103 - 1	10.4	3	2	Passing cloud.
72	19/11	1810	= 109	10.9	3	1.	
73	22/11	1751	119 +1	11.8	3	2	Hazy.
74	20/12	1911	114 +2	11.2	3	2.	

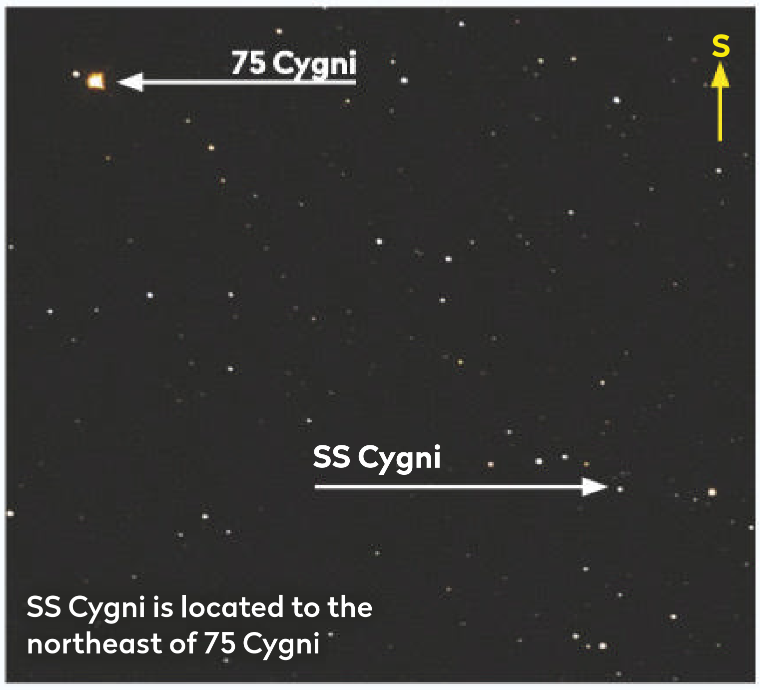
NASA/CXC/M.WEISS/SCIENCE PHOTO LIBRARY, PAUL ABEL, CHARTS BY PETE LAWRENCE X 2

Five late-summer variables

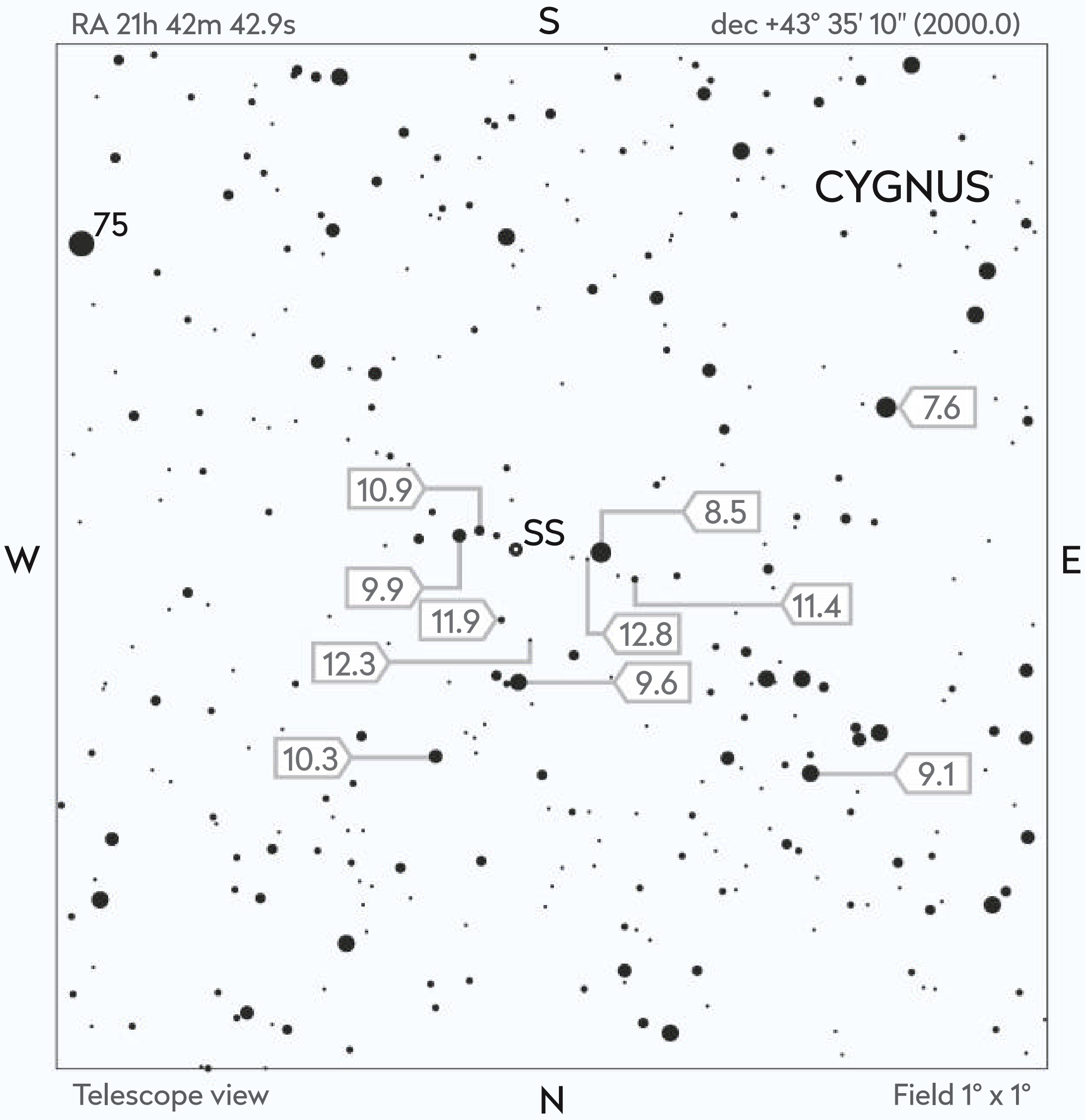
These examples are an ideal test-bed for your powers of observation

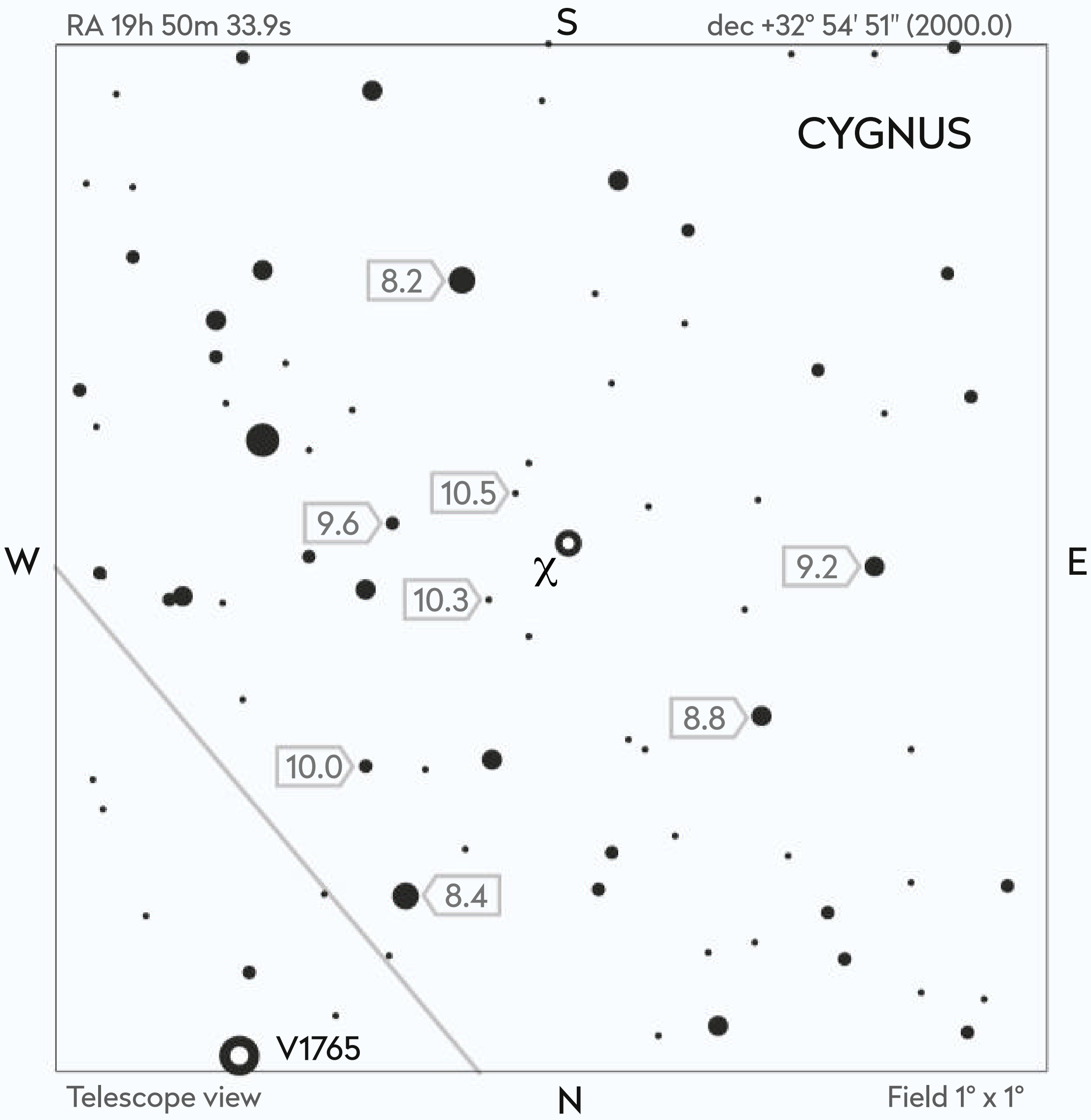
SS Cygni ▷

SS Cygni is a dwarf novae that resides in the constellation of Cygnus, the Swan, not far from the nice double star 75 Cygni. When it's quiescent (in a state of inactivity), the star is approximately mag. +12.0, but during an outburst it can brighten to about mag. +8.0. SS Cygni undergoes these outbursts every seven to eight weeks, so should be checked out whenever there's a clear night.



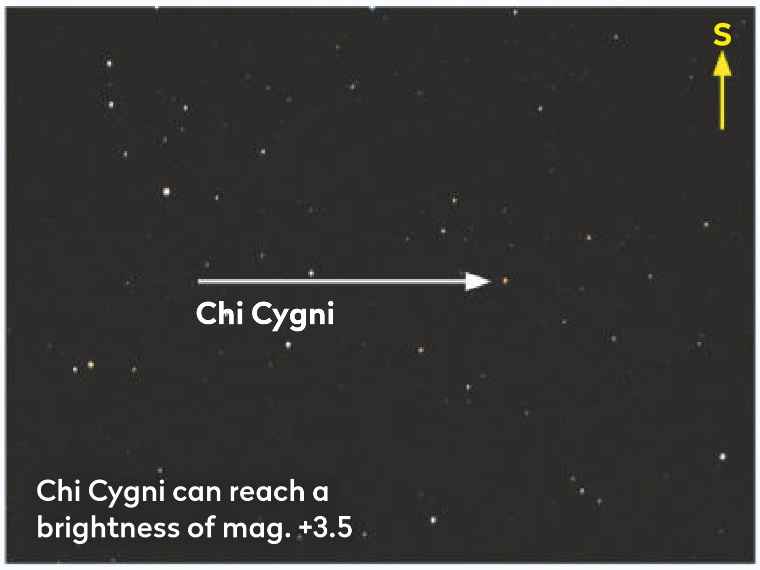
SS Cygni is located to the northeast of 75 Cygni





◁ Chi Cygni

Located fairly close to Eta (ε) Cygni at the base of the 'Northern Cross' asterism in Cygnus, Chi (χ) Cygni is a splendid red giant of the Mira type. Over a period of about 400 days, Chi Cygni can get as bright as mag. +3.5, before fading down to a minimum around mag. +14. Chi Cygni is throwing off material into space, material that will eventually form a planetary nebula. Aim to observe this star once a week, if possible.



Chi Cygni can reach a brightness of mag. +3.5

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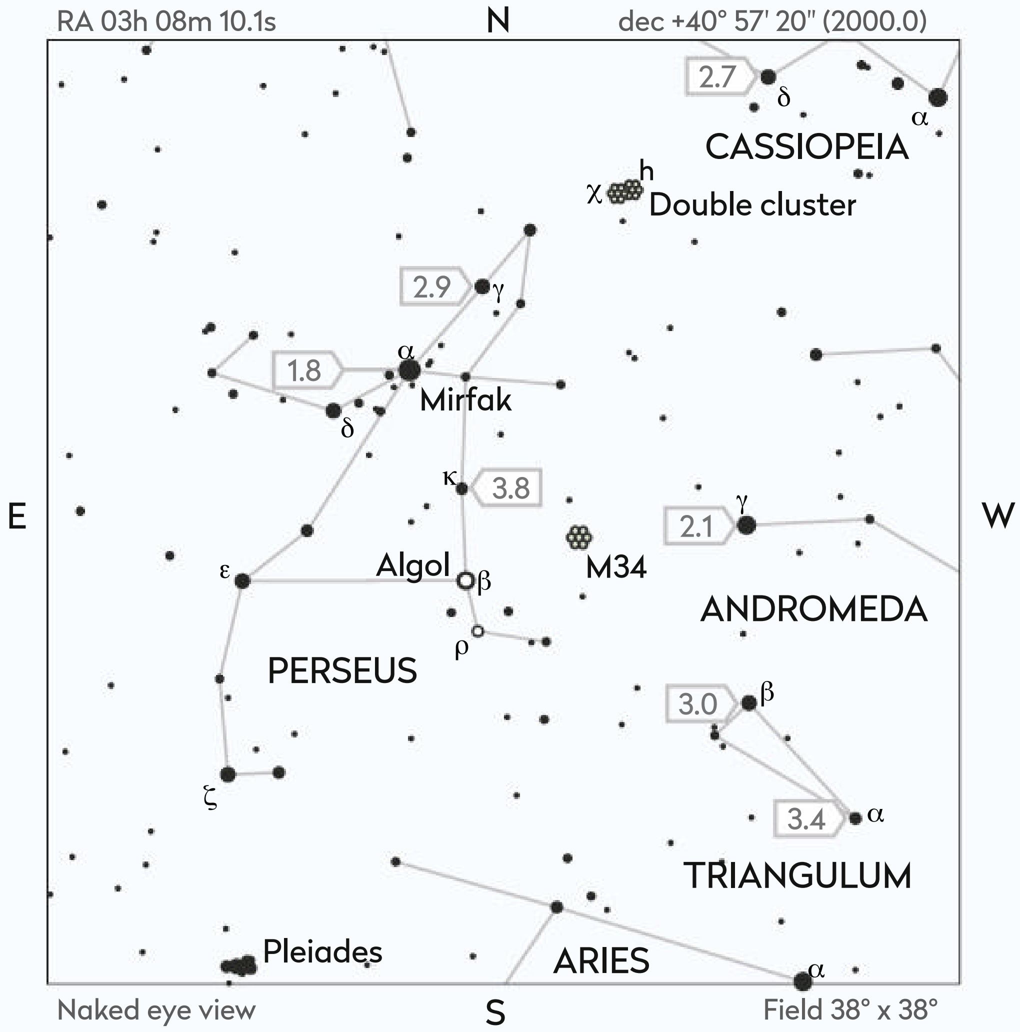
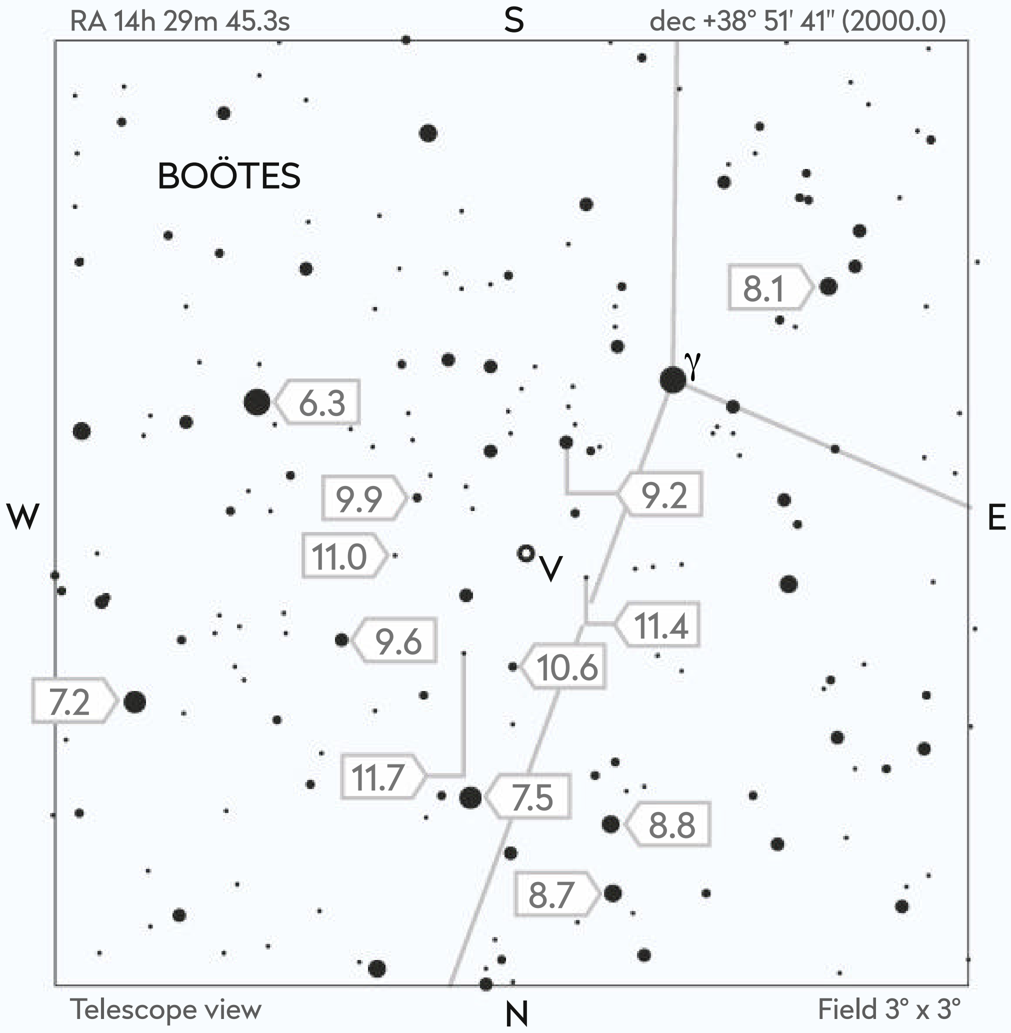




△ Algol

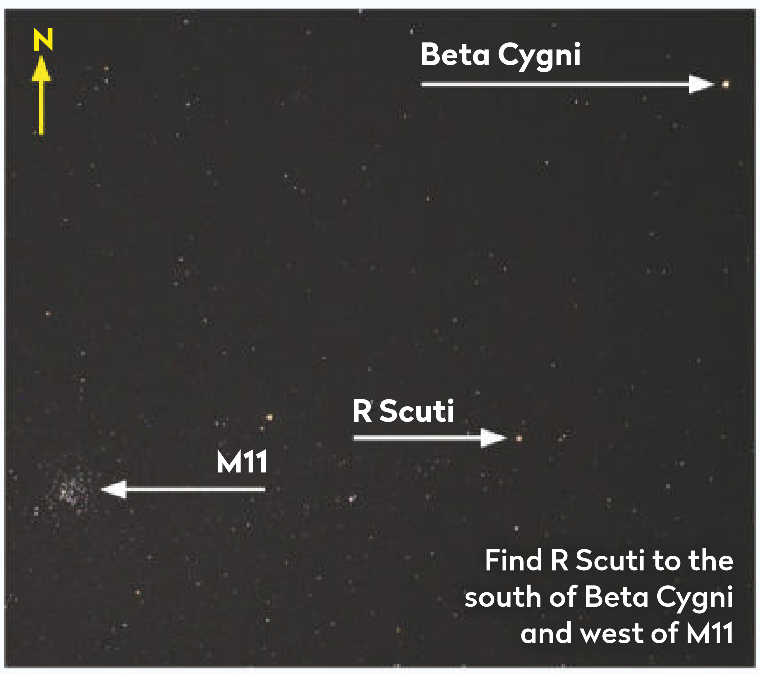
This is an example of an eclipsing binary system – Algol (Beta (β) Persei) is, in fact, composed of three stars: Beta Persei Aa¹, Beta Persei Aa² and the fainter Beta Persei Ab. It's the two hot primary stars, Beta Persei Aa¹ and Beta Persei Aa², that eclipse each other and these eclipses take approximately 10 hours. Algol is usually around mag. +2.1, but every 2.9 days it drops to mag. +3.4. Try to observe it each clear night.

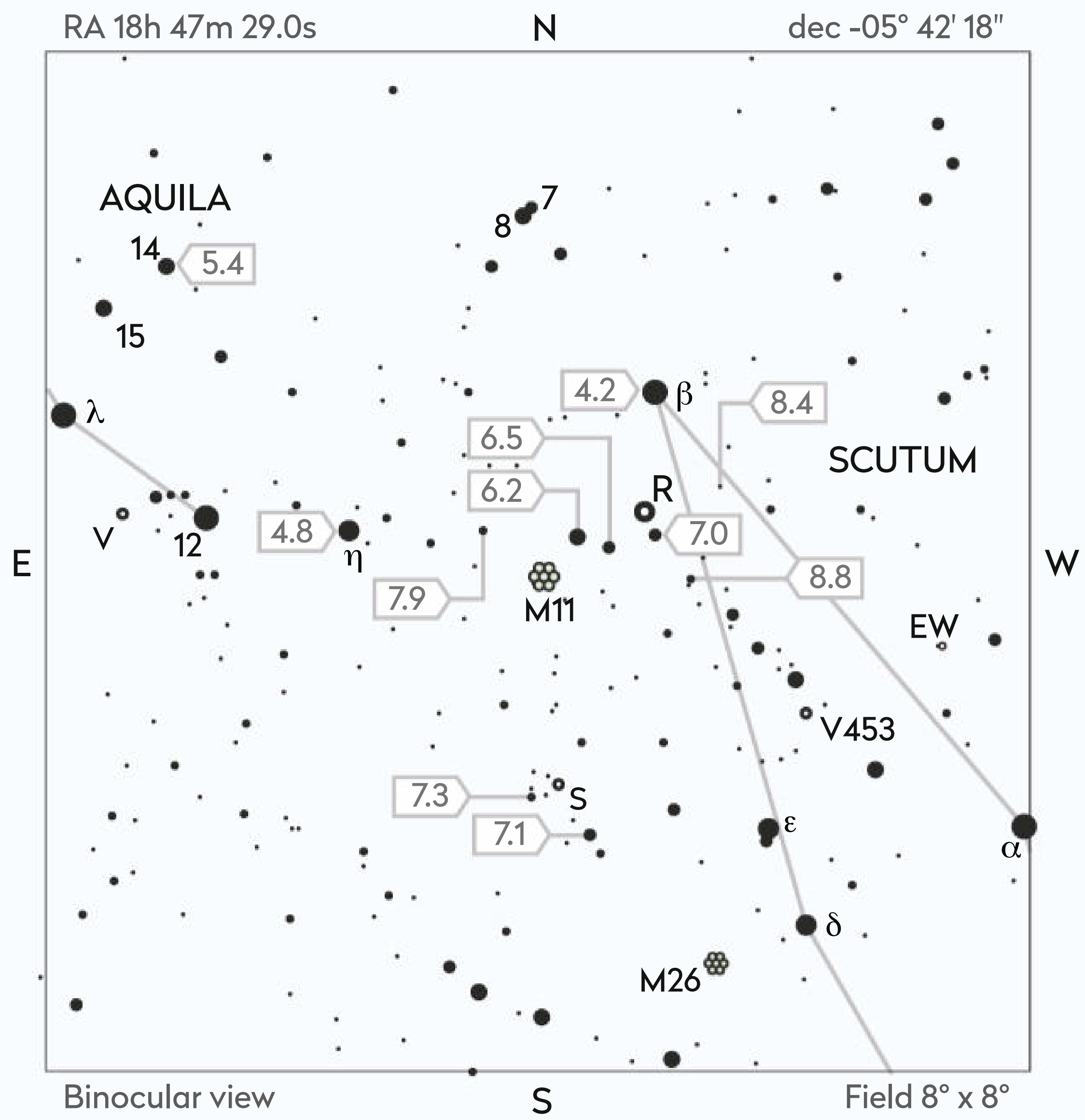
△ V Bootis

Another beautiful red giant, in Boötes, the Herdsman, close to Seginus (Gamma (γ) Boötes). This star ranges from around mag. +7.0 to mag. +12.0 over a period of 258 days. Studies of the light curve suggest that there's a secondary period of about 137 days, and during the early part of the 20th century the overall light curve was somewhat different (the star could be evolving away from being a Mira-type star). Aim to observe it once a week.

R Scuti ▷

This yellow supergiant star is an example of a RV Tauri variable. It lies close to both Beta (β) Scuti and the splendid Wild Duck Cluster, M11. The light curve for this star is quite remarkable and shows periods of deep minima and unusual 'stand-stills', during which its magnitude is constant for long periods of time. It's thought that the dynamics of the star are responsible, but there are many questions yet to be answered. Observe this star every chance you get.





CHARTS BY PETE LAWRENCE

Equipment and resources

The essential kit you need for a productive night of observing variable stars

▲ Keep your night vision preserved with a red-light torch

Red light

An essential bit of kit! White light will destroy your night vision and distort your magnitude estimates. Your eyes must be dark adapted when you're observing variables.

Binoculars or a small telescope

There are a few naked-eye variables, but many hundreds are in the range of binoculars or a small telescope. A selection of low- to medium-power eyepieces is also useful.

Comparison charts

It's essential that the correct star charts are used for magnitude estimates. You can get charts from the British Astronomical Association (**britastro.org/vss**) or the American Association of Variable Star Observers (**aavso.org**). The charts provided by these organisations have carefully chosen comparison stars listed. Each chart has its own name (called a chart sequence). Magnitudes of the comparison stars on AAVSO charts have no decimal point (which could be confused as a star), while the magnitudes of stars on BAA charts are given by letters to prevent bias.

A notebook

You'll need to keep a record of your magnitude estimates for each variable star you observe. You should include: the name of the variable star, the date, time (in Universal Time), the chart sequence of the chart containing your comparison stars, your estimate and the deduced magnitude of your star.

A laminator

Laminating your charts will protect them against dew and save you from printing a new chart every clear night.

Online resources

Check out the BAA at **britastro.org/vss** and AAVSO at **aavso.org**. Both organisations allow you to download charts and generate light curves. There's help with different aspects of variable star observing, and you can upload your observations as you make them.

▸ So if your comparison star is mag. +10.3 and you think the variable is four-tenths brighter, you'd record it as '103 – 4'. This notation means that the comparison star is of mag. +10.3 and that you estimate the variable to be about four-tenths brighter (by convention, you exclude the decimal point). Based on this estimate, the variable has a magnitude of +9.9, as mag. +9.9 is 0.4 times brighter than mag. +10.3.

If instead the variable was about six-tenths fainter, you'd record '103+6' and the deduced magnitude would be +10.9. You can repeat this with other comparison stars in the field to get two or three estimates and then take an average. You can find more detailed explanations of the Pogson step method on the American Association of Variable Star Observers (AAVSO) and the British Astronomical Association (BAA) websites (**aavso.org** and **britastro.org/vss**), along with an alternative, known as the Fractional Step method.

Light curves

Repeating your observations over time will give you a series of magnitudes for the variable star and when you plot these on a graph (with dates on the horizontal axis and apparent magnitudes on the vertical) the result is called a light curve. These are unique to each star, although similar types of variables have similar light curves. This is the main aim of variable star observation and the more observers that contribute magnitudes for a given star, the more accurate the light curves become. You can plot light curves from your observations on the AAVSO or the BAA websites.

The light curve is key to understanding a variable's behaviour. From this, we can determine how frequently the star is varying (its period), and the long-term study of light curves often provides hints of other astrophysical processes that may be at work. From the light curve of SS Cygni we know that there are two types of brightening, one that lasts less than 12 days and others that last a lot longer.

It's not uncommon for variables to throw up some surprises – they may get brighter or fainter than usual (Betelgeuse for example). Alternatively, they might remain quiescent for unusually long periods of time (the star R Coronae Borealis experienced an unusually long period where it was very faint, dipping below mag. +14; at the time of writing it's about mag. +6.0). All this tells astronomers that something interesting is going on and adds to our theories of stellar evolution, or our understanding of accretion theory.

Finally, it's really important to report your observations to the Variable Star Section of the BAA or the AAVSO. Both organisations allow you to enter your observations via an online form. The BAA in particular has been collecting amateur observations of variable stars since 1890 and has a number of pro-am collaborations.

Your long-term observations of variable stars are part of an invaluable resource – most professional telescopes are engaged in large fundamental observing campaigns, and it would be quite impossible to use them for long-term measurements of the many thousands of variable stars known to exist. By observing and recording variables, you'll be contributing to the only long-term narrative professional astronomers have of these objects, and doing so will help us answer the many questions that remain regarding the private lives of these stars.

Paul G Abel is the director of the British Astronomical Association's Mercury and Venus section. He's also a theoretical physicist at the University of Leicester

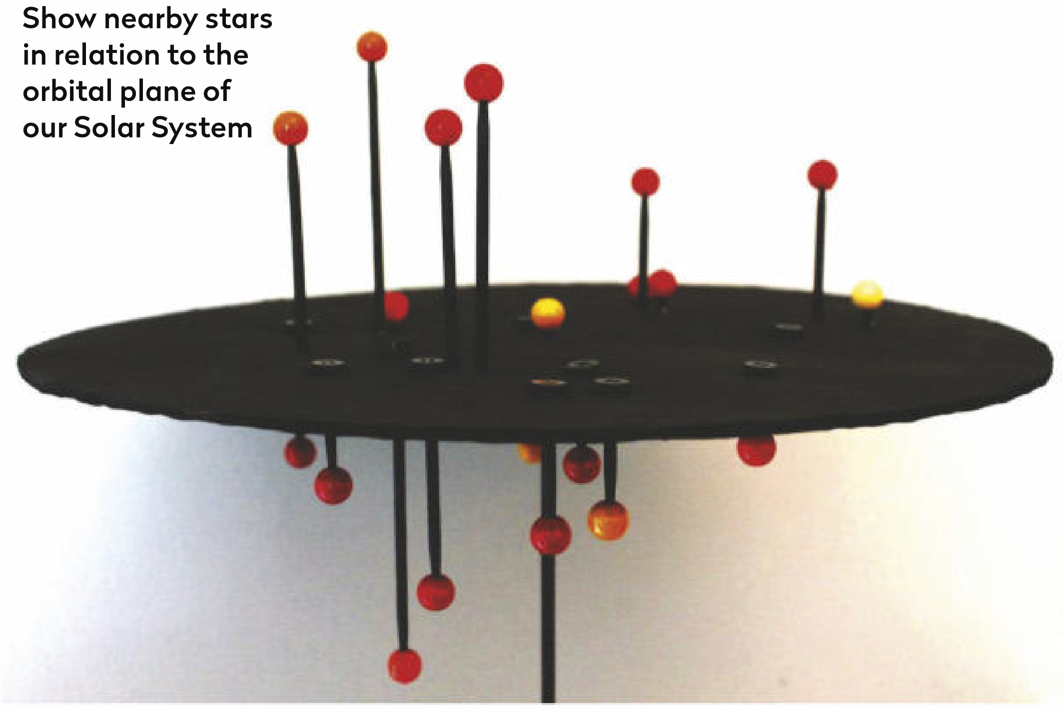
Practical astronomy projects for every level of expertise

DIY ASTRONOMY

FAMILY FRIENDLY PROJECT

Make a 3D model of our nearest stars

Get to know the distances between the Sun and its closest stellar neighbours



Show nearby stars in relation to the orbital plane of our Solar System

For this fun project we create a three-dimensional model that shows where the nearest 20 stars to our Solar System are located. It places the Sun at its centre and gives you a unique perspective of our nearby stellar neighbourhood. It doesn't just consider the distances of the stars, but gives their real coordinates relative to the orbital plane of the Solar System, which allows you to see exactly where the nearby stars lie relative to our Sun. We achieve all this by using basic materials and the project is packed with learning opportunities for your family.

The stars are colour-coded depending on their spectral class, so you can discuss the differences between the classes and explain that although 76 per cent of stars in our stellar neighbourhood are 'M class' (with a temperature up to 3,420°C), most are too faint to be seen with the naked eye.

Placing the stars

To work out the placement for the stars, we first downloaded the Astronomy Nexus star database from **www.astronexus.com/hyg**. We imported it into Excel and sorted the stars by distance and then selected the nearest 20. For the stars that are double or triple star systems, we represented the brightest star of that system. The database gives you *x*, *y* and *z* coordinates for each star as seen from Earth – the *x*-axis is horizontal and the *y*-axis is vertical, with the Sun's location represented by the point at which the two axes intersect. The *z* value represents each star's distance above or below the plane of the Solar System. These values are in parsecs, with 1 parsec = 3.26 lightyears. We multiplied each value by our scaling factor, 1 parsec = 3cm applied in all directions, so the model's diameter covers 30 parsecs. Don't worry if this sounds complex; we've done the maths in a downloadable spreadsheet (see below for instructions). The stars are numbererd 1 to 20 for ease of reference and the *z* values have had 4mm added to allow for the thickness of the cardboard disc.

We mapped the *x* and *y* coordinates onto the flat disc first and then used barbecue skewers (painted black) trimmed to the correct length to represent the *z* coordinates. The stars, represented by coloured beads (also painted beforehand), were attached to the skewer ends. Our stars in this project are not to scale – if they were, they would be microscopic!

We displayed the model on a simple stand so it is aligned with the plane of our Solar System, but you could easily adapt it to be a hanging model.

Mary McIntyre is an outreach astronomer and teacher of astrophotography

MORE **ONLINE**

Download a spreadsheet of stellar neighbourhood measurements. See page 5 for instructions.

What you'll need

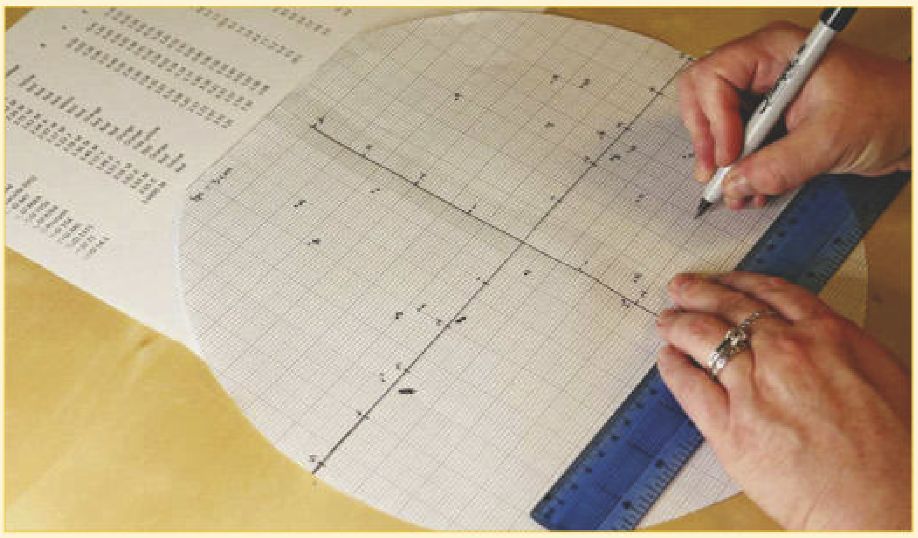
- A piece of sturdy cardboard, measuring 30cm x 30cm, plus a piece of graph paper the same size – we stuck two pieces of A4 graph paper together.
- Use 21 wooden barbecue skewers; 20 of 3mm diameter for the stars and a thicker one of 4mm diameter for the stand and the Sun.
- You'll also need 20 small black buttons, which will be glued to the ends of the skewers to act as stops for each star (excluding the Sun).
- Find 21 beads that fit onto the pointed ends of the skewers; you'll need 12 red, four orange, three yellow (including one for the Sun), one pale yellow and one white.
- A small, sturdy box to use as a base for the stand; ours measured 7cm x 8.5cm x 4cm.

ALL PICTURES: MARY MCINTYRE

Step by step

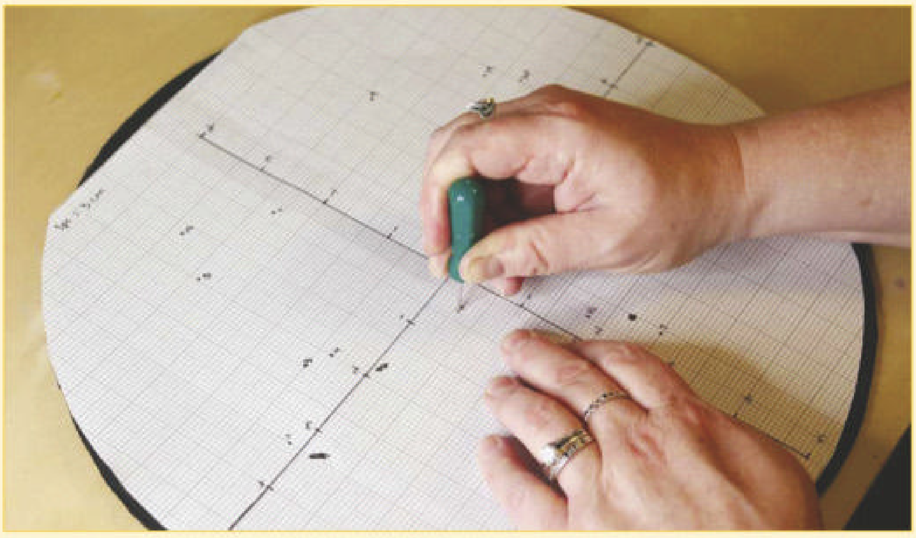
Step 1

Draw and cut out a 30cm-diameter circle from the sturdy card. This is the base plane of the Solar System and where the star skewers will be added later. Next, paint it black – we used spray paint, but you can use any water-based paint.



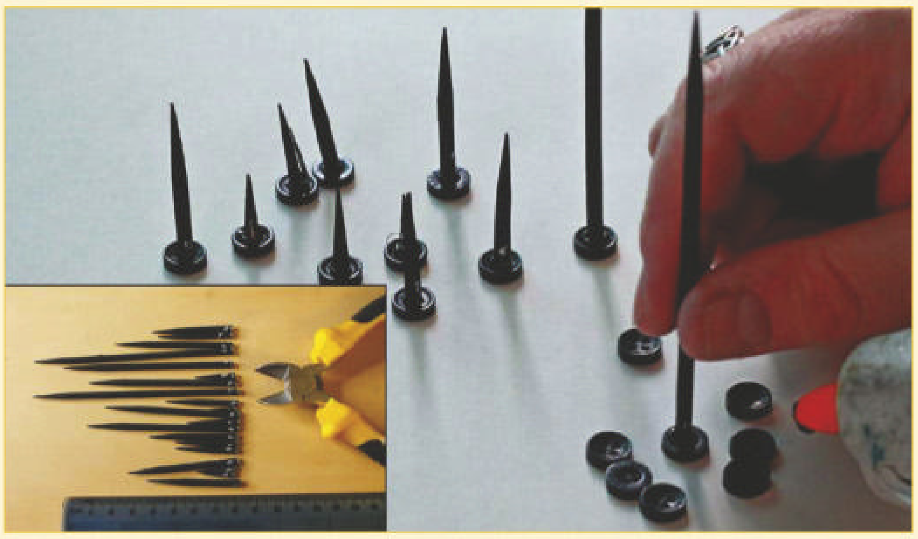
Step 2

Make a duplicate circle from graph paper; from the centre point, draw *x* (horizontal) and *y* (vertical) axes in a cross shape, extending 15cm each way. Using the values in our downloadable table, mark the *x* and *y* values for each star and label them.



Step 3

Place the graph paper over the cardboard circle. Using a small awl or push-pin, poke a hole through the paper and into the card at the centre point and everywhere you plotted a point on the graph. Label the holes 1 to 20 with a pencil.

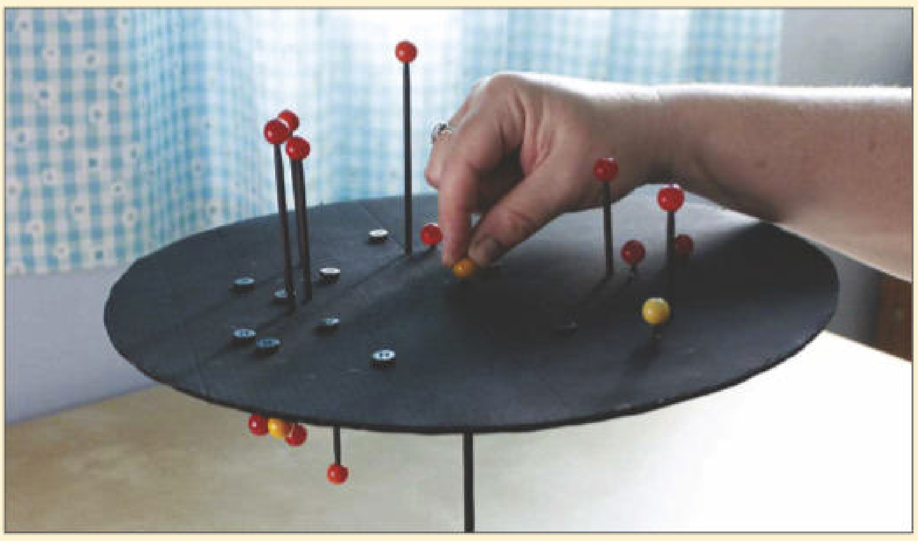


Step 4

Using the z values from the table, cut the star skewers to length to represent the distance above or below the plane of the Solar System, labelling them 1 to 20 as you go. Use a hot glue gun and a black glue stick to glue a button onto the cut end of each skewer.

Step 5

Poke the numbered skewers through the corresponding numbered hole, remembering that a negative z value should be pointing downwards and a positive value points up. Add the correctly coloured bead to each skewer, securing it with glue.



Step 6

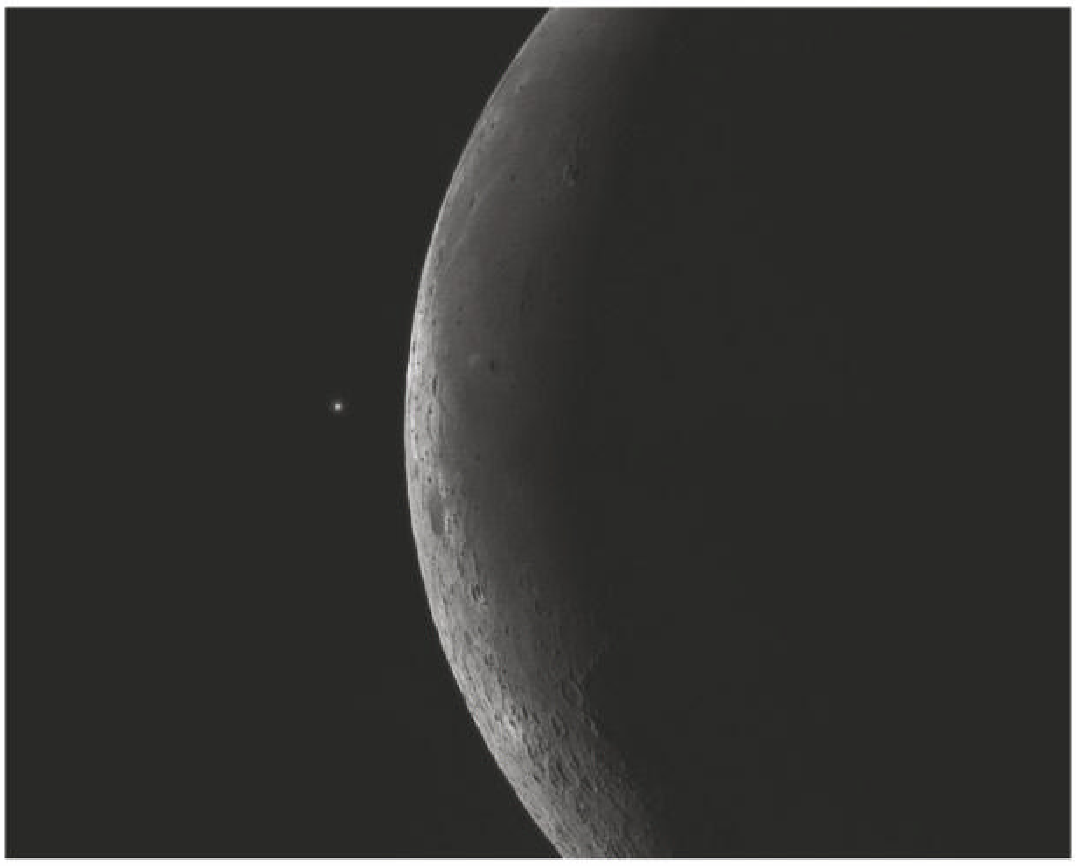
Cut the larger skewer to 26cm; push the pointed end into the centre hole and attach the final yellow bead to the top for the Sun. Make a small hole in the base box and poke the skewer into it. A blob of Blu Tak inside will help to hold it more securely.

Take the perfect astrophoto with our step-by-step guide

ASTROPHOTOGRAPHY CAPTURE

Imaging an occultation

Capture two lunar occultations of naked-eye stars, on the mornings of 2 and 3 September



▲ **With a stills camera you can take a series of shots of a star near the bright edge of the Moon, which can help refine the shape of its profile**

The term occultation describes when one body is hidden or occulted by another. This could be Jupiter passing in front of one of its four Galilean moons, or an asteroid passing in front of a star. A total eclipse of the Sun is technically an occultation of the Sun by the Moon. A more commonly witnessed type of occultation occurs when the Moon moves in front of a star, hiding it from view and then revealing it again as the Moon tracks east against the starry background. Two well-timed lunar occultations of naked-eye stars in Gemini occur on the mornings of 2 and 3 September, providing a great opportunity to view these events.

Timing occultation disappearances and reappearances can help provide information about the occulting body. Asteroid occultations have a degree of imprecision to them due to tiny unknowns in the position and shape of the asteroid. Showing that an asteroid occultation is visible from a specific location on Earth helps refine the asteroid's position, while accurate timings for the disappearance and reappearance of the star help us determine its shape. Similarly, accurate timings of a lunar occultation can help us to refine the shape of the Moon's limb.

If you have a stills camera, taking a photo of a star near to the edge of the Moon is straightforward. With the star in frame and the camera lens or attached telescope focused, it's possible to get a sequence of shots showing the Moon moving towards it or away.

With a planetary camera setup, it's possible to obtain an accurate timing for the event. Many control software options will record detailed logs of capture sessions, including the start and end time, and frame interval. Using a captured video of an occultation disappearance or reappearance will permit accurate timings of the key events to a fair degree of accuracy.

A similar result may be obtained with the movie mode on a DSLR, although lower sensitivity and a less accurate camera clock may lessen the precision.

Reappearing act

The events on the 2nd and 3rd occur in the early hours, the Moon being in its waning crescent phase; its bright edge will be doing the hiding, the stars reappearing from behind the dark limb. A bright edge brings exposure into consideration; set the sensitivity of your camera too high and you'll have a dominant bright over-exposed Moon in your shots. The reappearance is much easier to deal with in this respect, but of course the issue here is whether you have the right part of the Moon's limb in the field of view, and if you are recording your movie sequence at the right time to catch the star reappearing.

▸ **For more on lunar occultation events, see page 46**

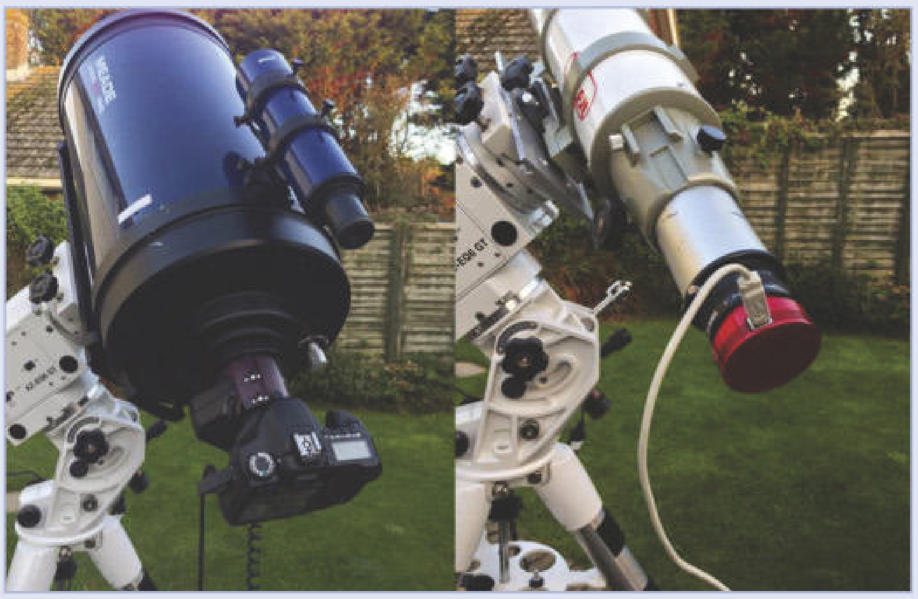
Recommended equipment: a telescope on a driven mount, a planetary camera

Pete Lawrence is an expert astro imager and a presenter on *The Sky at Night*

Send your images to: gallery@skyatnightmagazine.com

ALL PICTURES: PETE LAWRENCE

Step by step

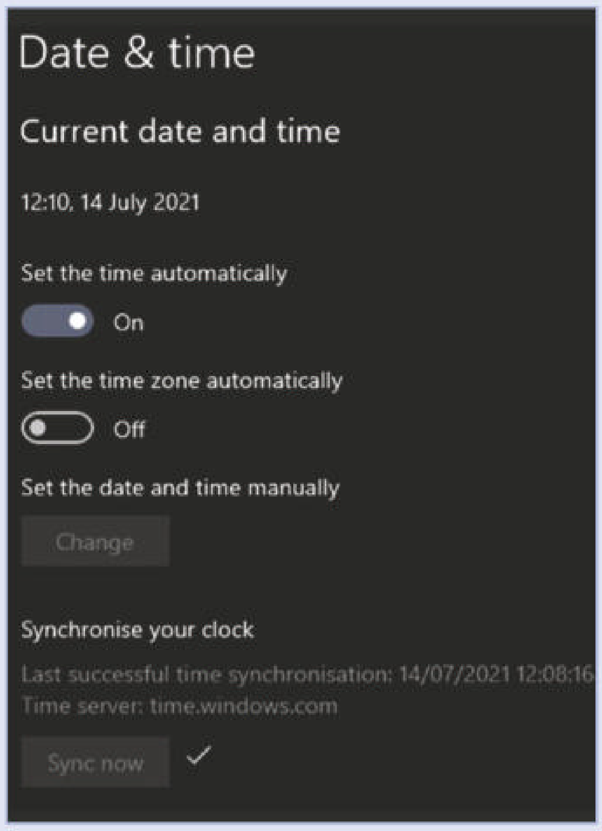


STEP 1

Select the type of camera; a DSLR or other type of stills camera can deliver a decent result, but an accurate timing can be tricky. The occultation disappearance on 2 September takes place at low altitude and may be distorted by seeing. A high frame rate device overcomes seeing effects, and has better timing accuracy.

STEP 2

The longer the effective focal length, the narrower the field of view. DSLRs will also typically offer larger fields than high frame-rate cameras. Decide whether you want to image with all the Moon's surface in view or to zoom into the region of interest. Wider field setups take the pressure off for the reappearance event.

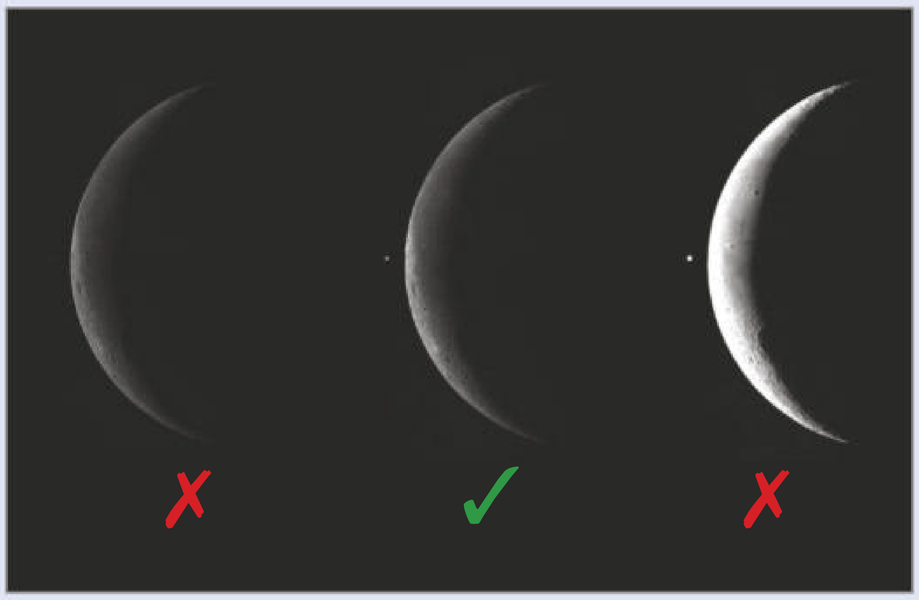


STEP 3

If you plan on making a timed event recording, it's essential that the DSLR's clock, or the onboard clock of a computer being used to control a high frame rate camera, has been synchronised to an internet time server. Time server examples include **time.google.com** and **time.windows.com**. A computer's operating system normally offers synchronisation options via its 'Date and time' settings.

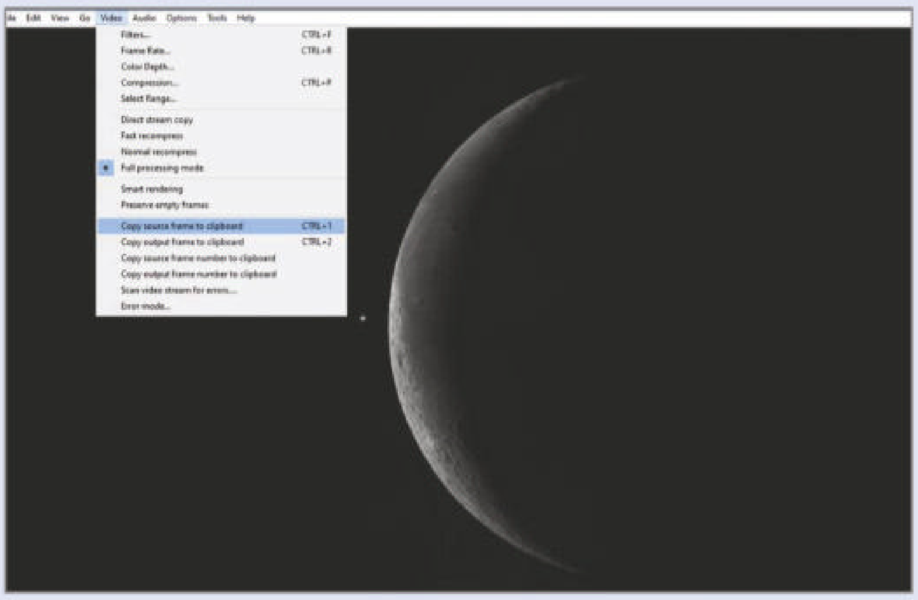
STEP 4

Accurate focus is essential for occultation images. Fortunately, for lunar occultations of bright stars, you have two easy focus targets – the star which is being occulted and the Moon's surface. Take your time over focusing, and revisit the task several times before disappearance as well as reappearance.



STEP 5

Ensure the object being occulted is visible in your images. This can be done prior to disappearance, and a note of the settings should be made to ensure the same values are used for reappearance. Exposures should be kept less than 0.5s in length, and balanced with as low a gain (ISO) as possible to reduce noise.



STEP 6

Individual frames can be extracted from an AVI movie sequence using freeware such as VirtualDub (**virtualdub.org**), or PIPP (**bit.ly/3x2vCJ3**). In VirtualDub it's possible to step through the sequence, frame-by-frame, copying frames to the clipboard (Ctrl-1) to load in an image editor.

Expert processing tips to enhance your astrophotos

ASTROPHOTOGRAPHY PROCESSING

How stacking can transform deep-sky images

Use image-processing software to bring out the hidden details of galaxy targets

▲ After: the stacked and processed image of M81 (left) and M82 teases out detail from the famous galaxy pair in Ursa Minor

Before: our RAW galaxies image may look reasonable, but it can be transformed with stacking

At first glance a single RAW image can look quite good – just like our photo of M81 and M82 (above, right). But problems will soon come to light if you tried to process it further: you'd quickly find it would not contain enough data or depth, and the image would start to deteriorate. The way to get round this problem – and achieve a richer picture quality on faint deep-sky objects – is to stack a number of images together with image-processing software. You can improve the final image still further by adding calibration images into the stack to remove camera defects. In this article, we're going to look at how this can be achieved using Serif's Affinity Photo software, which includes a selection of useful stacking tools.

Affinity Photo features a selection of 'Personas', which each contain a workspace that features tools, settings and panels. Affinity's new 'Astrophotography Stack Persona' enables you to process RAW sub-images and feed in calibration files to produce a stacked image for further processing. By stacking images like this, you're adding the data together, reducing noise (unwanted artefacts), making it look a lot smoother and enabling you to take post-processing much further. This makes it easier to tease out hidden detail within the image, so it looks its best.

Dave Eagle is an astronomer, astrophotographer, planetarium operator and writer

ALL PICTURES: DAVE EAGLE

Everything's covered

Affinity Photo takes care of the whole job of stacking and post-processing images; you don't need any other software. Let's start by accessing the program's 'Astrophotography Stacking Persona' from the menu bar. Click on 'File › New Astrophotography Stack' and the 'Astrophotography Stacking Persona' window will open, displaying a black image. On the right-hand side of the window there are three levels of 'Studio Panels' (see Screenshot 1): the top one features (left to right) 'Histogram' and 'Navigator'; while the second features 'Files', 'Stacking Options' and 'RAW Options'. The third has 'Stacked Images', 'History', 'Channels' and 'Info'. We'll only be using the 'Studio Panel 2' during the stacking process here; click on the 'Files' tab to open it.

You can stack mono and colour RAW image files from most cameras in Affinity Photo, as well as FITS files produced by modern astronomy cameras. To select the images that need to be stacked, click the

'Add' button within the 'Files' panel. The default setting is to stack 'Light' frames; if this has been changed, make sure that 'Light' is selected from the drop-down menu (see Screenshot 2).

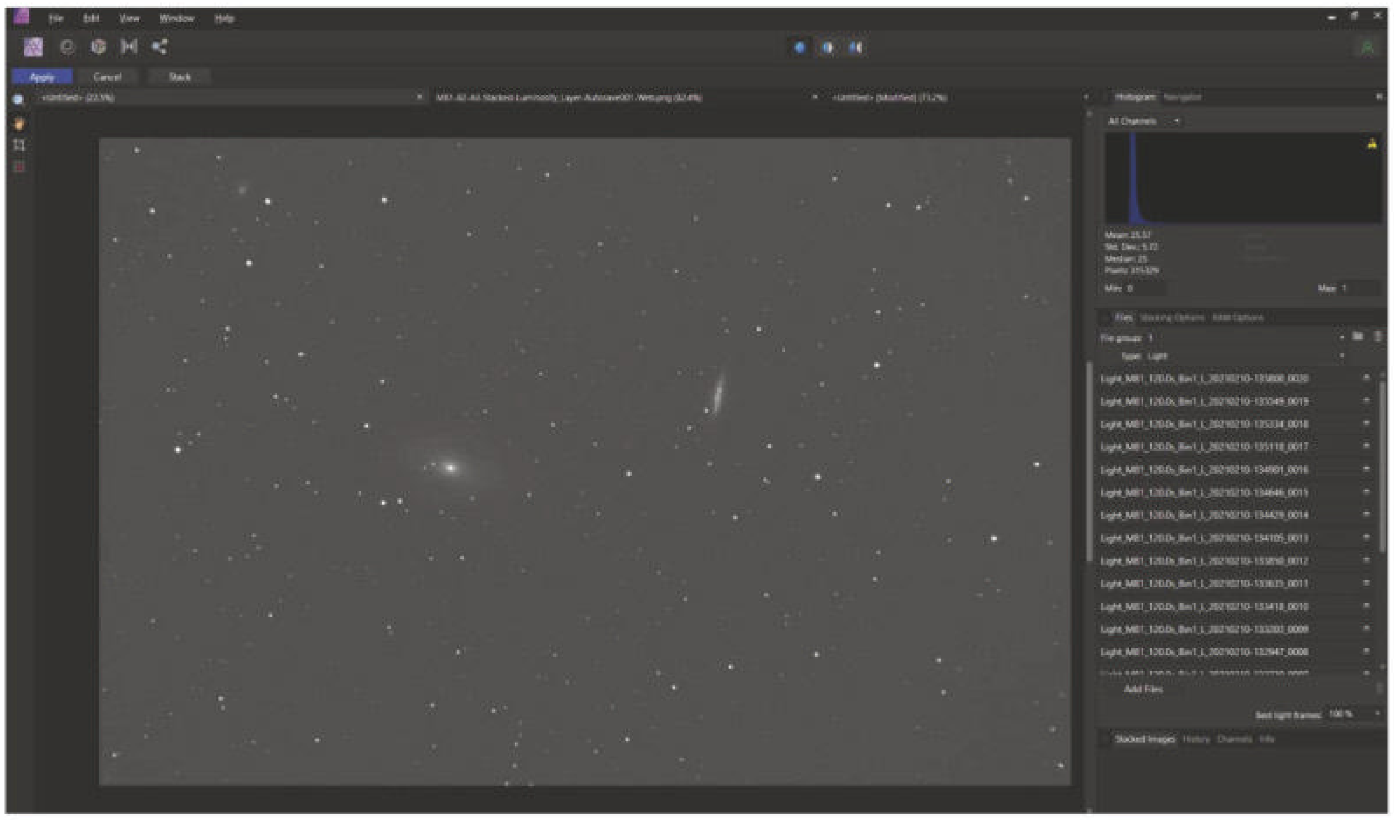
Next, click the 'Add Files' button, browse to the folder where the images you want to stack are stored, and select all the relevant files; then click 'Open'. The selected images will be loaded and displayed as a stack on the right-hand side of the 'Files' panel (see Screenshot 1).

By clicking on each image in turn, the selected image will be shown in the preview window. This enables you to inspect images for quality prior to stacking. If one is under par, you can select the file by clicking on it and then delete it from the stack by clicking the small dustbin icon. Calibration frames can also be added by selecting the relevant file type from the drop-down menu. These frames can remove amp glow, uneven light gradients, hot pixels or dust shadows.

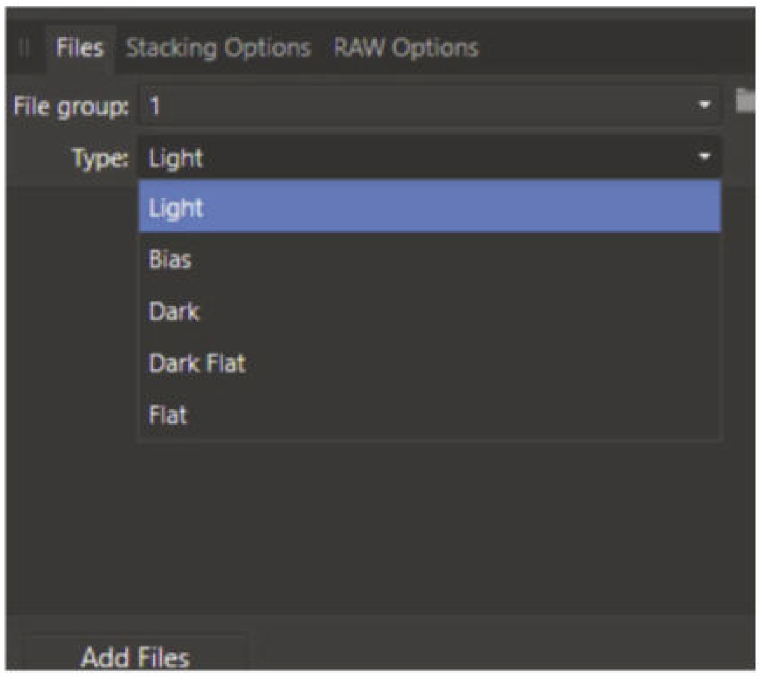
Once all the light frames and calibration frames have been added, there are a few more settings that need to be checked before the stacking process can begin. Click the 'Stacking Options' tab, to the immediate right of the 'Files' tab, and in the drop-down menu select the type of stack (see Screenshot 3). These methods include 'Mean', 'Median' and 'Sigma Clipping' modes. You can also adjust the 'Threshold and Clipping Iterations', if required.

Next, click on the 'RAW Options' tab, to the immediate right of the 'Stacking Options' tab (see Screenshot 3). Under the 'FITS Bayer pattern', you can select the specific Bayer Matrix that's built into your camera from the drop-down menu, for example 'Inferred', 'RGGB', 'GRBG', 'Mono' etc. The 'Demosaic method' can also be changed from 'Default' to 'Bilinear', and 'White balance' can be changed from 'Daylight', 'Camera' or 'Master Flat'. You may need to play with all these settings to get the very best results from the images. Once you have the right settings, click the 'Stack' button towards the top left of the main window (see Screenshot 1).

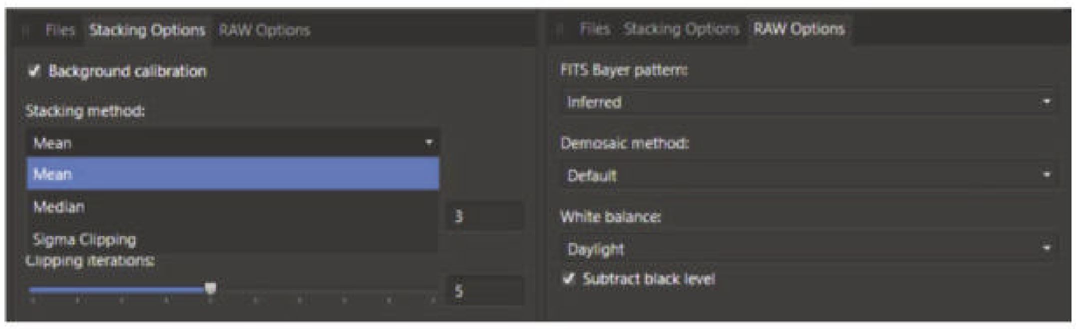
If you're only stacking a small number of images, you may not see that much happen at this stage. But once the stacking process has finished, click the 'Apply' button. The stacked image will now open within the software's 'Photo Persona', ready for further post-processing to bring out details for the final processed image. Our stacked and processed Luminance, Red, Green and Blue image of M81 and M82 (see main image, opposite) brings out much more detail than a single RAW image.



▲ **Screenshot 1: Within the 'Astrophotography Stack Persona' window, the images for stacking are displayed in the 'Files' panel on the right-hand side**



◄ **Screenshot 2: In the 'Files' panel make sure 'Light' is selected to stack light frames**



▲ **Screenshot 3: Select the type of stack required under 'Stacking Options' (left); and the 'FITS Bayer Pattern' for your camera under 'RAW Options' (right)**

3 QUICK TIPS

1. The 'Sigma Clipping' stack mode helps to eliminate aircraft and satellite trails.

2. A single FITS file can be opened and stacked on itself, for direct viewing or further processing within Affinity Photo's 'Photo Persona'.

3. The 'Levels Adjustment' and 'Curves Adjustment Layers' automatically added to the image can be adjusted or removed to suit your processing requirements.

Your best photos submitted to the magazine this month

ASTROPHOTOGRAPHY GALLERY

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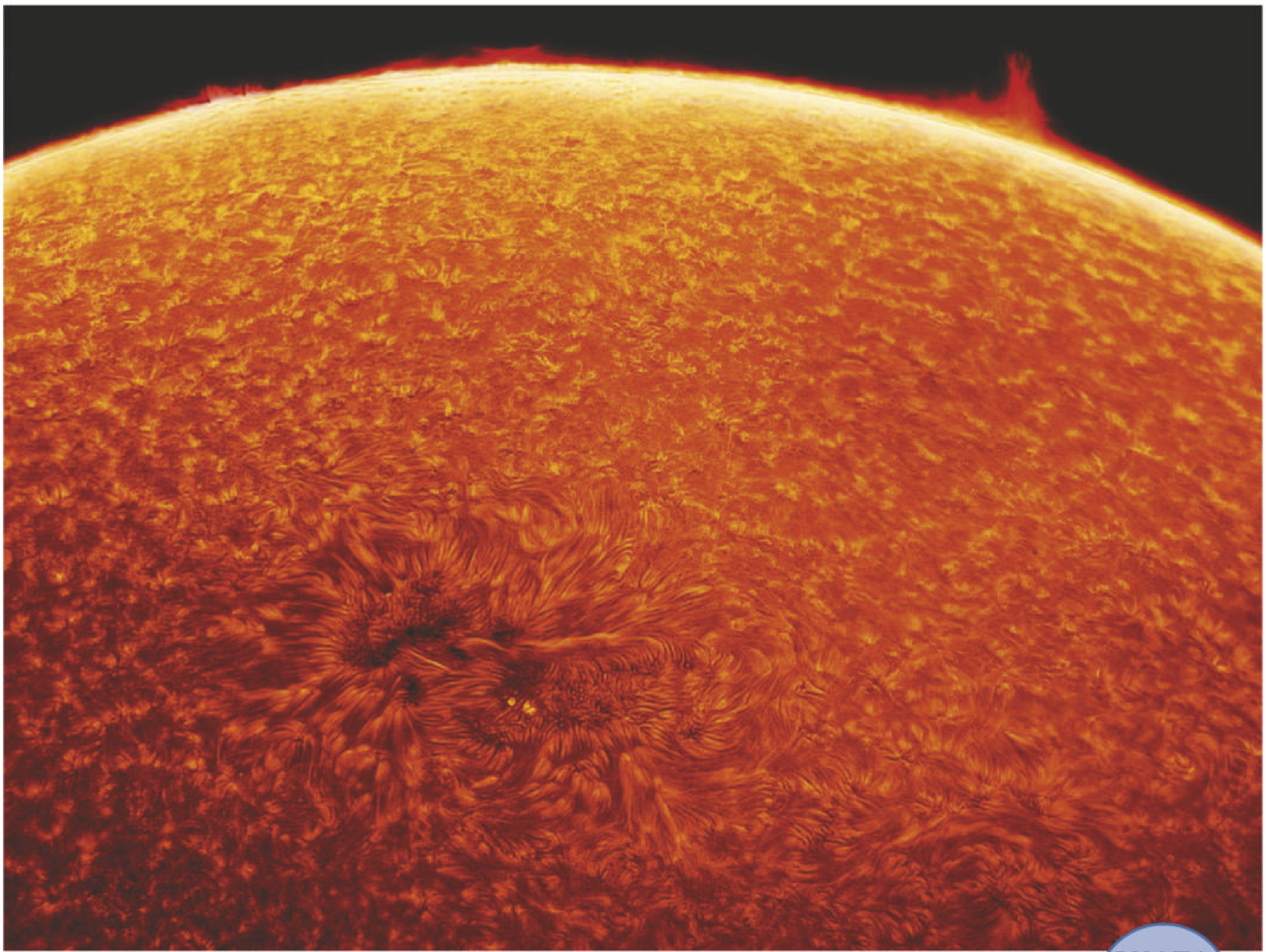


PHOTO OF THE MONTH

△ The Sun's sunflower

Alex Dean, Nottingham, 6 June 2021

Alex says: "As soon as I realised that you can take amazing images of our closest star, I was completely hooked. It isn't an easy subject to image by far, but the results speak for themselves. This is an image of AR2829, one of several new active regions we can see now the Sun is waking up from its period of inactivity."

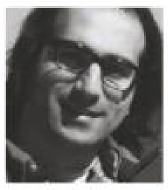
Equipment: ZWO ASI174MM camera, William Optics GT81 refractor, DayStar Quark Chromosphere eyepiece, Celestron CGEM mount
Exposure: 4,000 frames at 10ms
Software: FireCapture, AutoStakkert! ImPPG (Image Post-Processor)

Alex's top tips: "Apart from being a daytime activity, solar imaging is similar to planetary imaging, so with the right equipment it shouldn't be too much of a change. Imaging in the morning and over fields has proven to be the least disruptive atmospherically. I use a high frame rate mono camera so I can take 3,000–4,000 frames at around 10ms.

Once you have used AutoStakkert! for stacking, a great program to use for editing is ImPPG. Of course, never, ever look at the Sun directly through a telescope."

△ The Whirlpool Galaxy

Kasra Karimi, Aylesbury, 18–19 April 2021

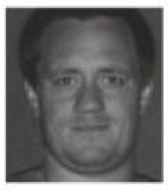


Kasra says: "I often drive out of the city to escape London's light pollution, camp and set up my telescope, even if it's in the middle of winter."

Equipment: ZWO ASI 6200MC camera, TS-Optics 130mm apo triplet, Sky-Watcher EQ6-R Pro mount **Exposure:** 75x 300" **Software:** PixInsight, Photoshop

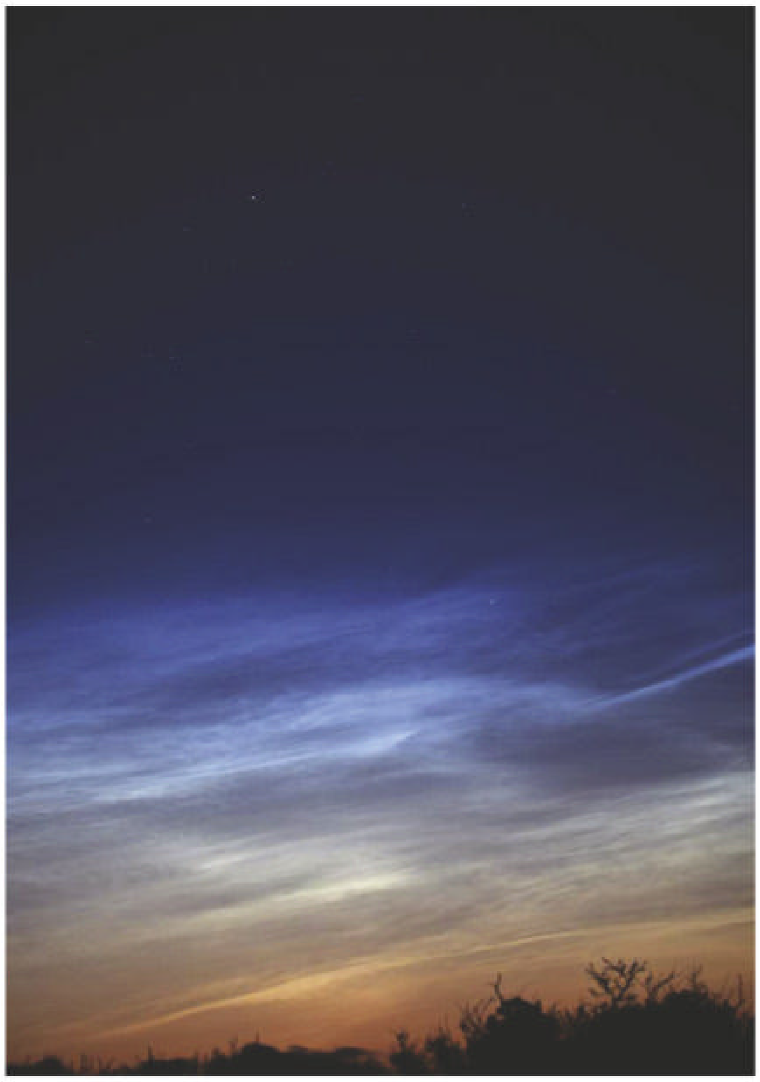
▽ The Leo Triplet

Jared Bowens, Clarksdale, Missouri, US, 27 March–23 April 2021



Jared says: "This was taken from my backyard observatory in Missouri, where I'm lucky to have exceptionally dark skies."

Equipment: Canon 60D DSLR, Orion 8-inch Newtonian astrograph, Celestron AVX mount **Exposure:** 15.8h total **Software:** PixInsight, Photoshop



△ Noctilucent clouds

Hannah Rochford, Gower, 4 June 2021

Hannah says: "I've never seen [NLCs] before and I couldn't believe how beautiful they are! It was around 11:45pm and they came out of nowhere on a very clear night."

Equipment: Canon 5D Mk II DSLR, Sigma 150–600mm lens **Exposure:** ISO 500, f/5, 10" **Software:** Photoshop

◁ The Pelican Nebula

Ian Phillips, Weston-super-Mare, 12 June 2021

Ian says: "This was only my second time using my new Esprit 120ED. Opportunities were at a premium, thanks to the short hours of darkness and only two nights of clear skies in two months."

Equipment: ZWO ASI2600MC Pro camera, Sky-Watcher Esprit 120ED refractor, Sky-Watcher EQ6 Pro mount **Exposure:** 24x 5' **Software:** PixInsight

Jupiter and Galilean moons ▽

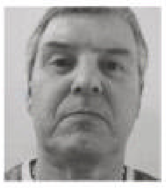
Paul Sparham, Leatherhead, Surrey, 6 May 2018

Paul says: "I was interested in your article 'A beginner's guide to planetary imaging' (June issue 2021, p60), particularly how you can use just a humble smartphone. This setup can still yield good results."

Equipment: iPhone 5S, Orion XT6 Dobsonian **Exposure:** 1,500 frames, with best 500 stacked **Software:** AutoStakkert!, GIMP

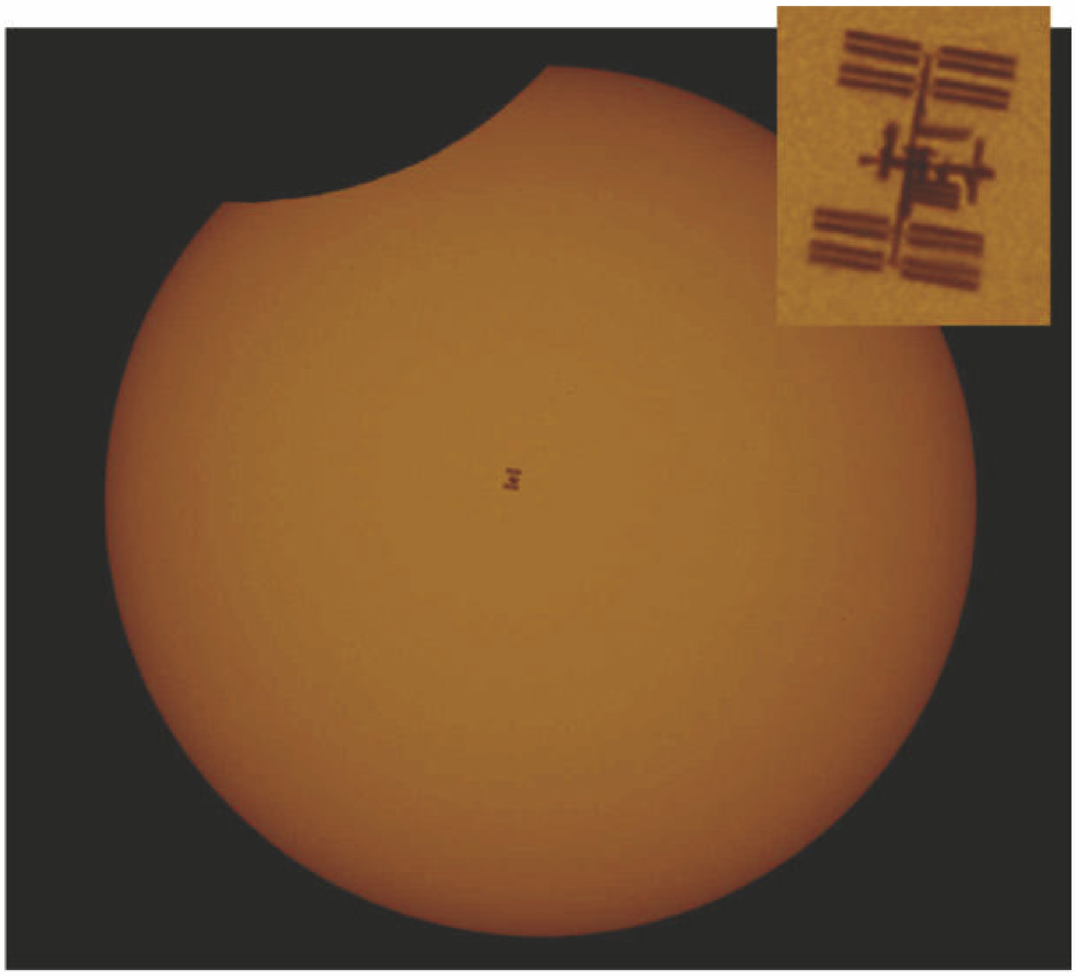
The Rosette Nebula ▷

Tony McAvoy, Camborne, Cornwall, December 2020 to January 2021



Tony says: "I've spent hours trying to master the art of post-processing with PixInsight. It seems to be paying off."

Equipment: QSI 583WSG camera, William Optics GT81 refractor, Sky-Watcher HEQ5 Pro mount **Exposure:** Ha 10h, OIII 8h, SII 8h **Software:** SGPro, PixInsight



△ Eclipse and the ISS

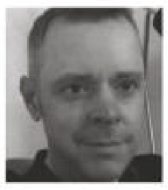
Antoine Thibault, Pontarlier, France, 10 June 2021

Antoine says: "After a two-hour drive and delays at the border for COVID checks, I managed to reach my spot in a cereal field. I missed the start of the eclipse, but I was on time to catch the ISS transiting the Sun – it took less than a second."

Equipment: Canon R5 mirrorless camera, Astro-Physics 130mm refractor, Astro-Physics mount **Exposure:** ISO 100, 1/8000" **Software:** Photoshop

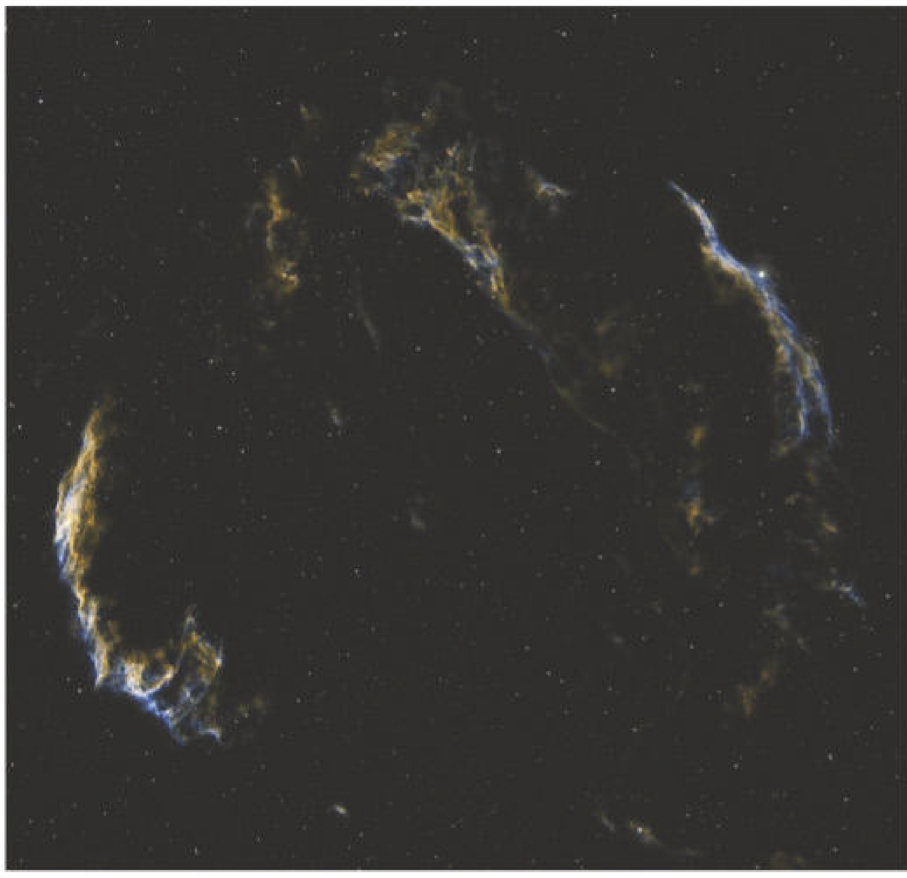
▽ The Veil Nebulae

Matthew Clough, Selby, North Yorkshire, 23 June 2021



Matthew says: "For processing, I used a bi-colour channel combination and the lightness curve to tease out the details of the nebulosity."

Equipment: ZWO ASI 294MC Pro camera, William Optics RedCat 51 refractor, Sky-Watcher HEQ5 Pro mount **Exposure:** 31x 120" **Software:** PixInsight, Affinity Photo



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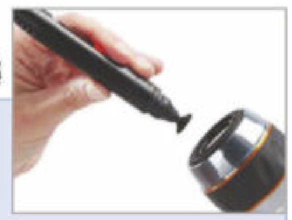

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86

An eyepiece-free telescope? We put Unistellar's innovative eVscope eQuinox to the test

PLUS: Books on the big cosmological questions and the Space Race, plus a roundup of essential astronomy gear

HOW WE RATE

Each product we review is rated for performance in five categories. Here's what the ratings mean:

★★★★★ Outstanding ★★★★☆ Very good
★★★☆☆ Good ★★☆☆☆ Average ★☆☆☆☆ Poor/avoid

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Our experts review the latest kit

FIRST LIGHT

Unistellar eVscope eQuinox

A smart, eyepiece-free telescope that offers light pollution-beating views of the deep sky

WORDS: JAMIE CARTER

VITAL STATS

- **Price** £2,599 (plus £59 shipping)
- **Optics** 114mm (4.5-inch) reflector
- **Focal length** 450mm, f/4
- **Sensor** Sony Exmor IMX224
- **Mount** Motorised single-arm, altaz, Go-To
- **Power** In-built lithium-ion rechargeable (12-hour) battery
- **Tripod** Aluminium, adjustable height
- **Ports** USB-C for power, and USB-A for charging a smartphone
- **App control** Unistellar app for smartphones
- **Weight** 9kg
- **Supplier** Unistellar SAS
- **Email** contact@unistellaroptics.com
- **www.**unistellaroptics.com

Would you consider buying a telescope that doesn't have an eyepiece? On the face of it, Unistellar's eVscope eQuinox appears to challenge conventional wisdom by not including one, so we were keen to put it to the test.

When Go-To telescopes arrived 20 years ago they were hugely divisive; amateurs who had spent years learning their way around the sky felt cheated that anyone could now access the same deep-sky gems instantly. But it's now rare to find a telescope without Go-To capability – and the hobby has blossomed.

The Unistellar eVscope eQuinox is the latest version of the 'smart' digital telescope and is just as innovative. Like the original eVscope from 2020, the eVscope eQuinox is a 4.5-inch, f/4 reflector that comes with a camera sensor that tracks and stacks images in real-time to produce rich-colour views of deep-sky objects. In that respect, it's just like the ground-based optical telescopes used by professional astronomers.

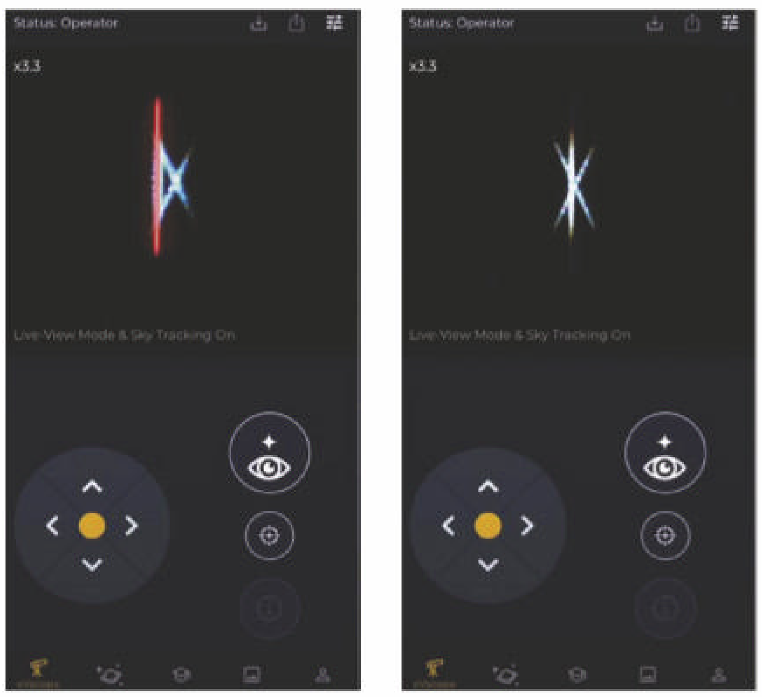
Everything the eQuinox does is accessed through Unistellar's app, so to view the sky with it you need a tablet or smartphone; up to 10 of these can be linked to the telescope via its Wi-Fi network. Your device receives the images the scope generates, which are refreshed every few seconds.

While the average 4.5-inch reflector will give you disappointing deep-sky views of galaxies, globulars and nebulae from urban areas, the eQuinox's image-processing power can counter the effects of light pollution. The Unistellar app also asks if you're in a city, a suburb or the countryside. Armed with that knowledge, it tweaks the in-app list of recommended objects, relegating any that are likely to succumb to light pollution beyond the eQuinox's capability. The limit in stellar magnitude that's visible with the eVScope is +18.0 for dark skies, but still a whopping +16.0 for urban areas. ▸

Look, no eyepiece!

The lack of an eyepiece on the eQuinox takes a little getting used to. To focus images, instead of using an eyepiece and the focusing knob at the base of the tube as on the original eVscope, you view the image on a tablet and use the Bahtinov mask inside the dust cap. Clicked into place across the telescope's tube and with the eVscope pointed at a bright star, you then manually tweak the focusing knob until spikes of light streaming through the mask's three distinctive cut-outs intersect as shown in the app view (see right).

The eQuinox can also be manually focused just as well using the Moon, but therein lies a distinct disadvantage of having no eyepiece; the eQuinox's magnification is fixed at a field of view of 30 arcminutes. So you can never quite get the whole of the Moon in view. But by removing the electronic eyepiece Unistellar has given this telescope two hours' extra run-time compared to the original eVscope. Given that some deep-sky objects, and certainly citizen-science tasks, benefit hugely from long observations, that's a worthy improvement.



▲ Focus is achieved in the Unistellar app by using a Bhatinov mask and a focusing knob at the tube's base

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Mount

The L-shaped altaz mount contains the motor, which moves the telescope into position and then accurately tracks objects. Inside the mount are also the built-in lithium-ion battery and the on-board computer. It features 64GB storage, four times more than the original eVscope.

Optical tube

The mirror and sensor are inside a tube that measures 65cm long and 23cm wide. The design incorporates a 114mm (4.5-inch) diameter mirror with a focal length of 450mm (17.7 inches), which gives a focal ratio of f/4. Light is focused directly onto a Sony Exmor IMX224 sensor in a spider vane on the front end.

Connections

There's an on/off switch that glows blue when switched on. The built-in battery pack is recharged via USB-C, which you can do using any portable battery. There's also a USB-A slot on the side so you can recharge a smartphone or tablet.

Tripod

The tripod is designed for the eQuinox; the tube mounts on a ring at the top and is secured by two screws. The three-part legs can stretch from 59cm to heights of 133cm when fully extended. The tripod weighs 2.2kg and is very sturdy.

Dust cap

The dust cap that sits on the front of the telescope's tube is there to keep it clean, but it's got the added bonus of containing a Bahtinov mask. When clicked into place on the front of the tube, the mask can be used to focus on a star while using the Unistellar app.

KIT TO ADD

1. A portable battery and USB-C cable

2. eVscope backpack

3. Twitter app, for sharing images in real-time

▸ With the eQuinox trained on the Whirlpool Galaxy, M51, you can watch as lanes of stars resolve: successive images add to the detail, clarity and brightness every few seconds. The time it takes to gather enough light to capture an object at its best depends on the object, sky transparency and light pollution.

For example, the Ring Nebula, M57, looked wonderfully bright and colourful after just 24 seconds. M51 was similarly impactful; its galactic arms gaining colour and definition the longer the eVscope was left to track and stack. Meanwhile, globular clusters – including M10, M13 and M71 – take only a few seconds to impress.

A view for sharing

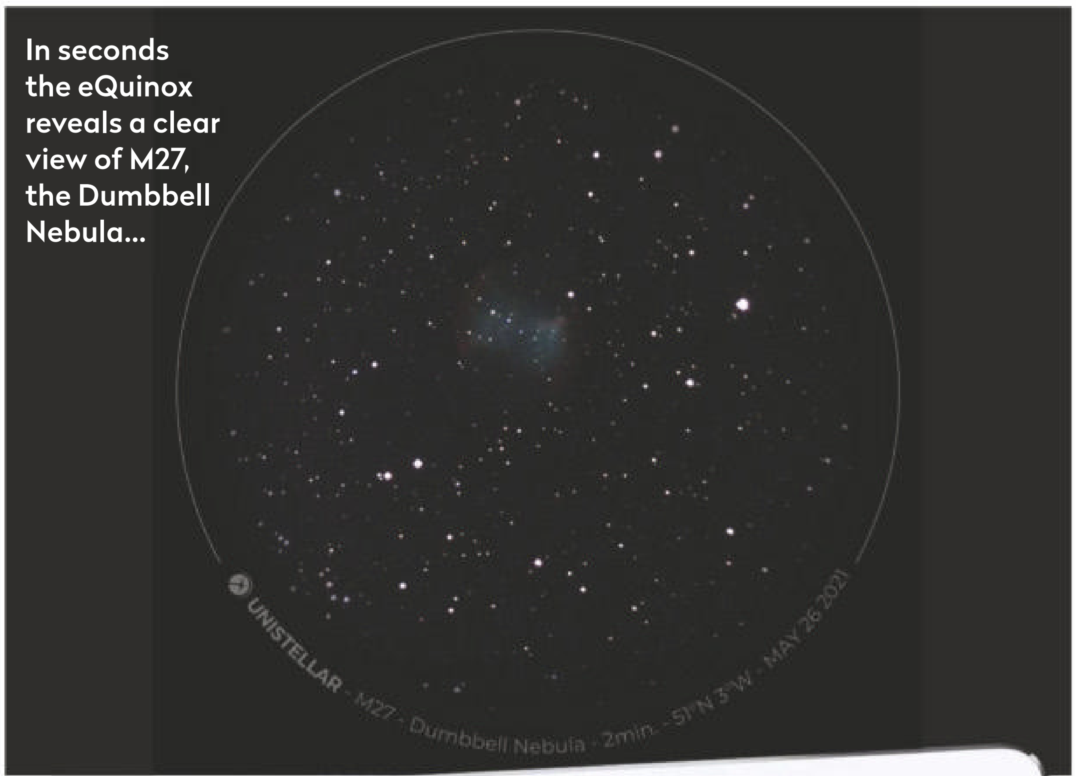
While the images produced by the eQuinox are ideal for viewing, sharing and learning (there are optional overlays of info), they do fall short of those that can be produced with an astrophoto-grade scope on an equatorial mount under a dark sky, over many hours. That said, a firmware update issued during this review increased resolution from 1.2MP (1,120 x 1,120 pixels) to a much more impressive 5MP (2,240 x 2,240 pixels).

Gain, exposure time and brightness can all be tweaked and captured images are saved as PNG files to a smartphone or tablet, with only RAW data left on the telescope. Regular uploading to Unistellar's servers is also recommended.

The eQuinox is extremely simple to set up and although its Autonomous Field Detection software makes initial alignment easy, it's fastest when the scope has first been manually pointed at a star-filled region of sky. The app is user-friendly and makes it simple to select targets.

It's also possible to manually enter coordinates of, say, a comet or a supernova that's recently appeared, although Unistellar periodically adds such targets to the app. It also has a citizen science dimension, asking users to observe asteroid occultations, exoplanet transits and 'planetary defence' tasks (potentially hazardous asteroids). Observational data can then be uploaded for analysis by scientists at Unistellar and the SETI Institute.

The eQuinox is an easy-to-use telescope that works very well in brightly lit urban areas, with the bonus of having a scientific aspect. It's a new type of telescope inspired by professional, ground-based telescopes – after all, the science of astronomy is doing just fine without eyepieces.



In seconds the eQuinox reveals a clear view of M27, the Dumbbell Nebula...

▲ ...and a view of the Whirlpool Galaxy, M51, shows impressive definition. In addition, the Unistellar app can display overlays of facts about targets

VERDICT

Build & design	★★★★★
Ease of use	★★★★★
Features	★★★★☆
Go-To/tracking accuracy	★★★★★
Imaging quality	★★★★☆
OVERALL	★★★★½

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Prof. Anne-Marie Minihane, University of East Anglia

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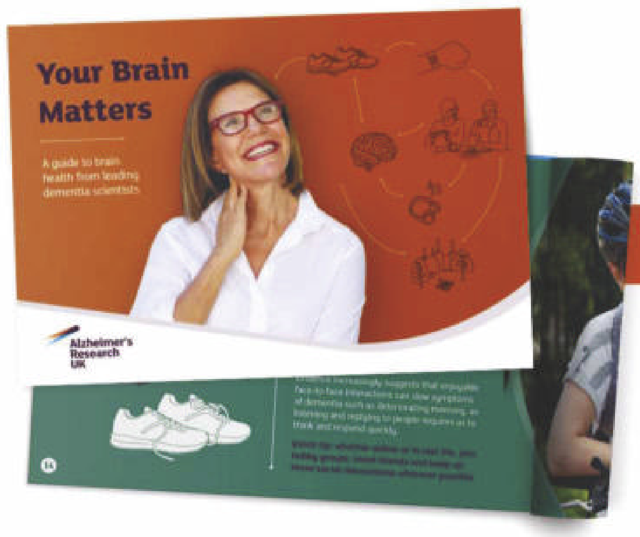

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Our experts review the latest kit

FIRST LIGHT

Founder Optics FOT106 triplet refractor

A telescope that delivers an impressive optical performance for observing or imaging

WORDS: TIM JARDINE

VITAL STATS

- **Price** £2,159 package with field-flattener (or £1,999 OTA only; optional field-flattener at £179)
- **Optics** Air-spaced apo triplet
- **Aperture** 106mm
- **Focal length** 636mm
- **Focuser** Rack and pinion
- **Extras** Field-flattener, carry handle, lens cloth, Inspection Report and owner's manual
- **Weight** 6.7kg (with tube rings; 5.5kg without)
- **Supplier** Widescreen Centre
- **Tel** 01353 776199
- **www.** widescreen-centre.co.uk

With an established reputation for quality and high-end performance, Japanese optical systems are held in high regard, so we received the new Japanese-designed Founder Optics FOT106 triplet refractor for review with keen anticipation.

The telescope is supplied in an aluminium case with useful accessories and our package included a matching field-flattener. From the outset we were impressed with the overall look of the telescope; the refractor is finished to a very high standard, with a distinctive gloss black tube and vibrant metallic green anodising for the fittings. We also noted that it weighs a reassuringly chunky 6.7kg thanks to its solid construction.

When it comes to optics, the FOT106 boasts an f/6 106mm objective lens with a focal length of 636mm, making it ideal for observing or photographing larger clusters, galaxies and nebulae. With the dew shield and focuser retracted the tube assembly is a compact 557mm in length. With the dew shield fully extended and a field-flattener plus camera – or star diagonal and eyepiece – attached, the telescope's working length is around 800mm.

Considering that there are three pieces of glass at the working end, it was nice to see that the balance point of the tube was reasonably central. This made it comfortable to use for observing, and easier on a mount for astrophotography.

Test conditions

Despite having the Inspection Report card, we were keen to do our own star test to confirm the findings. It was a warm evening, so we allowed plenty of time for the telescope to cool. Our Ronchi eyepiece returned an almost identical pattern to that on the report and demonstrated that there was no astigmatism or other glaring optical aberrations.

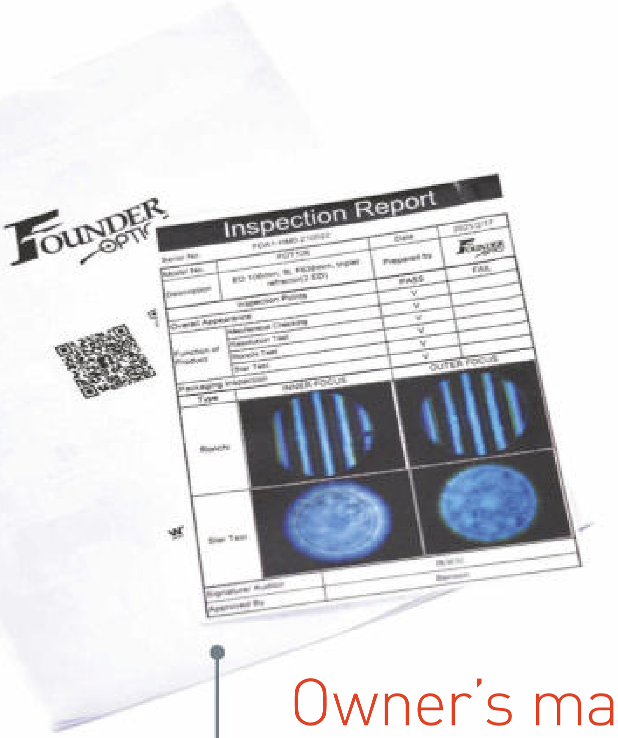
With a 4.5mm eyepiece working at 140x magnification, and then combined with a 2x Barlow lens to deliver 280x power, we observed a centrally positioned star and gently rolled through either side of focus, noting the star pattern. If anything, what we observed was even better than the artificial star test image given on the Inspection Report, with a ring pattern demonstrating a high level of correction. This ►

Air-spaced acuity

The FOT106 objective lens uses three distinct elements to achieve apochromatic colour correction, and two of these are made of extra-low dispersion (ED) glass, namely FPL-53 and FPL-51. Fully multi-coated to minimise reflections, these lenses are separated by air-filled spaces, an approach to lens design also adopted by Takahashi TOA telescopes.

Of course, performance with an eyepiece or a camera is what really counts. We viewed the bright edge of a near-full Moon at high power to check for any unwanted colour-fringing or haloes along the focused edge, an effect that can translate into coloured rings around bright stars in astro imaging, but the view was sharp and free of chromatic aberrations. Although suitable photographic targets from our observatory were limited by the time of year, we were able to grab a series of images of the Dumbbell, Veil and Eagle Nebulae. With their tight, natural-coloured stars these images confirmed the impressive optical abilities of the FOT106.

ALL PICTURES: @THESHED_PHOTOSTUDIO

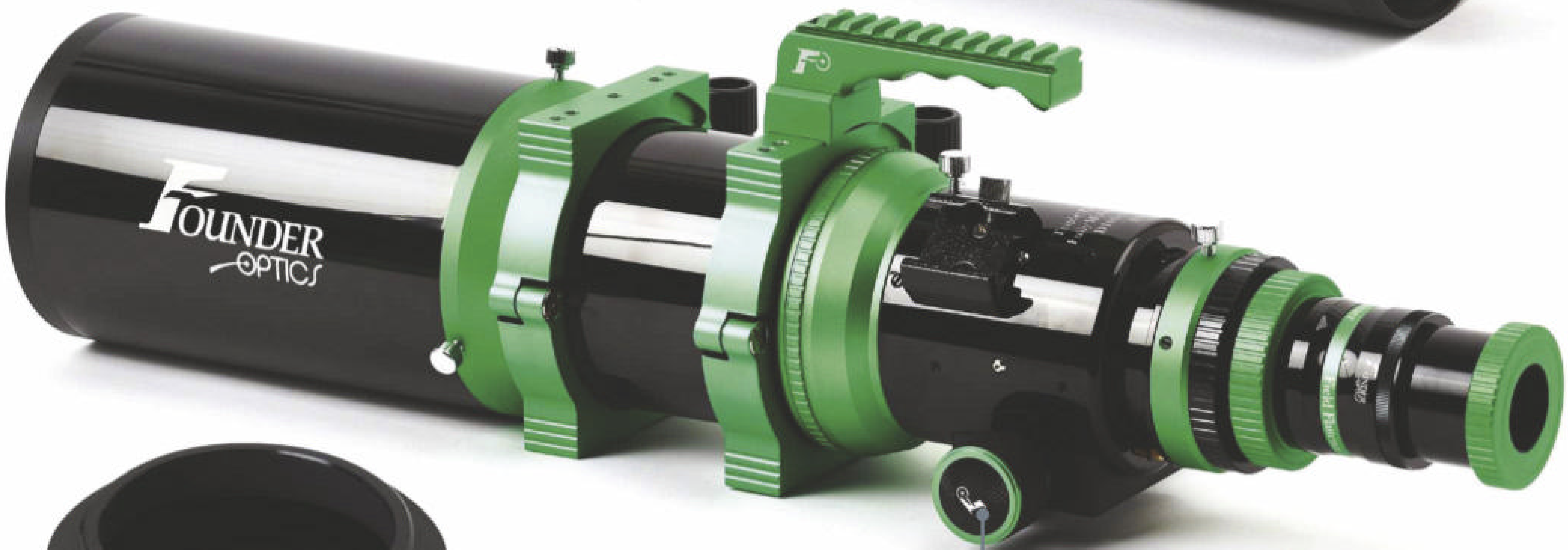


Tube rings and carry handle

Stylish green tube rings and a Vixen-style mounting bar provide a solid link between the FOT106 and the mount. A custom carry handle bolts securely onto the top of the rings and incorporates a mounting rail for a red dot finder. All the necessary bolts are included in the package.

Owner's manual and Inspection Report card

The underside of the focuser is stamped with a serial number, which matches that on the laminated Inspection Report and provides an individual verification of the scope's optical and mechanical quality. The printed owner's manual is a nice touch that gives tips on telescope-assembly, accessories and the correct use of the equipment.



Field-flattener

The inclusion of a matching field-flattener makes this telescope an almost out-of-the-box solution for astrophotography. It has a 2-inch nosepiece that is held firmly by the twist and lock collar on the focuser, and the M42– and M48–threaded adaptors for cameras offer a straightforward attachment to a CMOS camera or DSLR T-ring.

Focuser

The 2.7-inch focuser is a strong hybrid rack and pinion design, offering smooth, precise focusing with 1:11 reduction. Capable of holding 8kg, the drawtube is graduated and the whole assembly is easily rotated for comfortable viewing positions. In addition, the rear section rotates independently, allowing you to easily frame targets or quickly alter the positions of eyepieces.

FIRST LIGHT

KIT TO ADD
1. Baader SkySurfer V red dot finder
2. William Optics Dura Bright 2-inch Dielectric Carbon Fibre Diagonal
3. TeleVue 25mm Plössl eyepiece, 1.25-inch

▸ gave us confidence that the performance of the telescope should be excellent, and a visit to Epsilon (ε) Lyrae, the famous Double Double star, revealed a clean and distinct split between its four closely paired members.

With the FOT106 set up for observing we embarked on a tour of some of our favourite deep-sky objects. Our 13mm 100° eyepiece enabled us to enjoy some very comfortable viewing at 50x magnification, and with a range of globular clusters gracing the skies we were able to enjoy crisp, contrast-rich views of them in context, before switching to a 10mm eyepiece for a closer view. An immersive viewing experience with our 21mm 100° eyepiece was especially memorable, with the low magnification of 30x providing superb wide views. We added a visual OIII (Oxygen) filter to enhance the planetary nebulae M57 and M27, which were notably bright objects among a sea of stars.

Field-flattener option

Although we could have enjoyed the rewards of visually observing the skies for much longer with the Founder Optics FOT16, we were conscious of the summer nights during our review period not being particularly dark or long, so we removed the visual astronomy accessories and attached the field-flattener to our DSLR camera T-Ring via the M48 adaptor option that is provided.

The owner's manual states that the useful image circle, or circle of illumination, with the field-flattener in place is 44mm, something our full-frame DSLR would test to the limit. We photographed star-rich areas and looked carefully at the results.

Indeed, we found that the centrally placed stars were round and pin-sharp, as expected, while the star shapes towards the corners and edges of the image started to show the effects of coma, the stars becoming a little stretched and larger. As an estimate we would say that a crop of an area about 60–70 per cent of the full-frame image size will leave acceptable star shapes, which should be just about right for DSLR and CMOS cameras with APS-C-size sensors or smaller.

With an impressive optical performance both visually and with a camera, the Founder Optics FOT106 may be the next telescope to claim its place among the ranks of esteemed Japanese-designed optical equipment.

Carry case

The foam-padded, locking carry case protects the telescope in transit or storage, holding the complete package conveniently together, including the field-flattener and rings. At just 70cm x 24cm x 23cm the case is very manageable and enhances the portability of the FOT106 while travelling, perhaps to darker skies.

▸ **A single shot of the Moon, taken with the FOT106 refractor and a standard Canon EOS 6D DSLR (full frame) – with 1/640" exposure at ISO 100**

▾ **A cropped image of the Eagle Nebula, M16, taken with the same setup – with 1 hour 18 minutes of 60" exposures at ISO 1000**

▴ **The Great Cluster in Hercules, M13 (cropped), taken with the same setup – with 1 hour 17 minutes of 90" exposures at ISO 800**

VERDICT

Build and design	★★★★★
Ease of use	★★★★★
Features	★★★★☆
Imaging quality	★★★★☆
Optics	★★★★★
OVERALL	★★★★½

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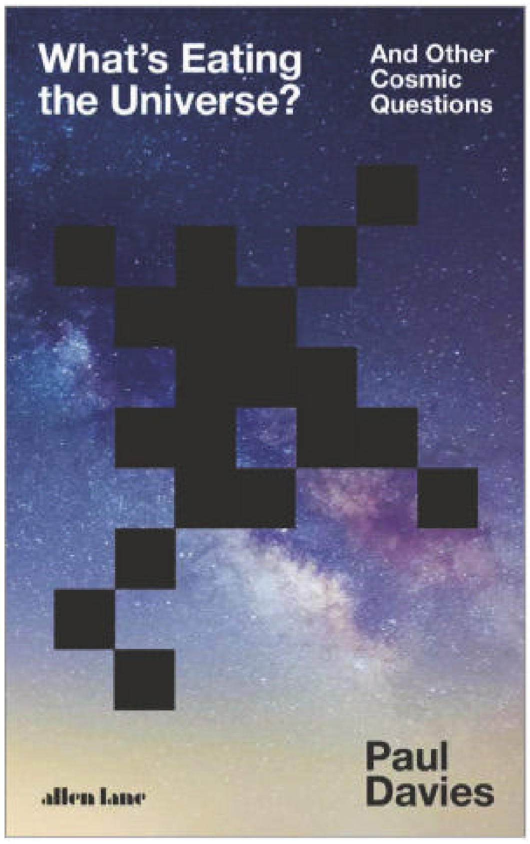
BOOKS



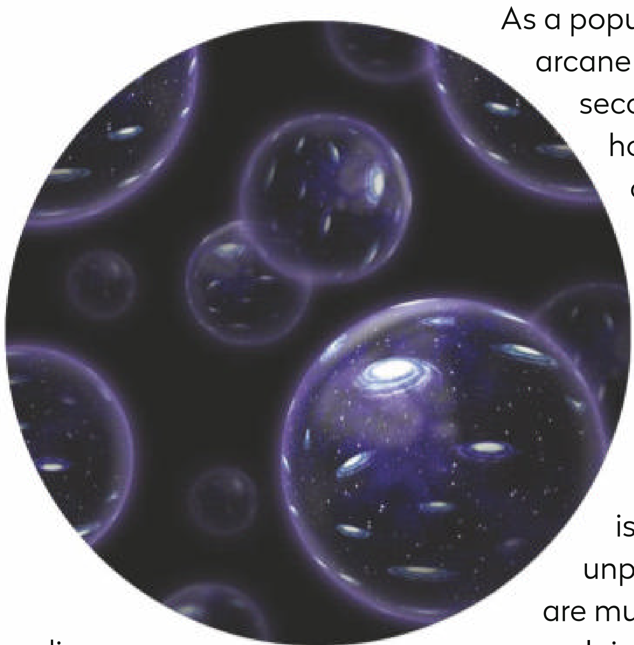
What's Eating the Universe?

Paul Davies
Allen Lane
£16.99 ● HB

It is little more than a century since the nature of gravitation, the abstractness of the quantum world and the true extent of the Universe were first perceived. But in that short time, the progress in our cosmological understanding has been staggering. We have deciphered the earliest moments and subsequent history of the Universe to such an extent that our insights about the origins of our own planet pale in comparison. Although this insight has been astounding, there are of course many mysteries still occupying modern astrophysics and cosmology.

In this rather short book, cosmologist Paul Davies takes us on a whistle-stop tour of some of these solved and not-so-solved topics. He propels us across the development of post-Einsteinian cosmology, often including his own modest contributions, as well as covering ideas about time and space, black holes, inflation, dark energy and dark matter. Davies's lucid style has allowed the book some freedom of movement and anecdotal diversion, giving the impression that a story is being told; although each chapter is a short vignette that can be read in complete isolation.

The final quarter or so of the book moves into slightly more speculative or philosophical areas of modern science. Davies discusses multiverses, the anthropic principle, life in the Universe, the eventual fate of the cosmos, the thorny topic of 'reductionism', and the meaning of science itself. These areas are covered with equal reserve and restraint, and complement the more definitive concepts previously introduced.



Concepts are skilfully discussed, including multiverses (above) and the meaning of science itself

FOTOJOG/ISTOCK/GETTY IMAGES

As a populariser of often arcane science, Davies is second to none. Having honed his skills in well over two-dozen books, there is little to fault in his style or his ability to reduce concepts to their minimum. Keeping it entertaining, the text is informative and unpatronising. There are much better books explaining our current views on dark matter, dark energy, inflation, multiverses, time travel, and so on. However, these are often more detailed and taxing than the armchair enthusiast requires. *What's Eating the Universe?* fills a niche nicely – it can be read in a single afternoon. ★★★★☆

***Dr Alastair Gunn** is a radio astronomer at Jodrell Bank Observatory in Cheshire*

Interview with the author
Paul Davies

What cosmological questions remain unsolved?

Did the Universe originate a finite time ago, or has something always existed? Or, to express it more bluntly, did time itself begin with the Big Bang?

What is the Cosmic Microwave Background (CMB)?

It is the fading afterglow of the Big Bang. When the Universe erupted into existence 13.8 billion years ago, it was immensely hot. That heat radiation suffused all space, but as the Universe expanded, the temperature declined, so that today it forms a pervasive background of microwaves, like a vast cosmic oven.

What might the 'super-void' be?

Cosmologists are stumped. It looks like something banged into our Universe, which is a rather outlandish theory, but who knows? More conservatively, the simple picture we have of inflation – when the Universe jumped in size by a huge factor in the first split second – might be an over-simplification, and some sort of quantum vacuum disturbance has left a blemish on an otherwise almost exactly smooth cosmic organisation.

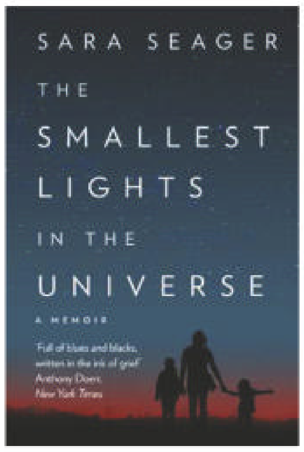
Where can cosmologists look to solve this mystery?

There are many theoretical models of the early Universe, some involving either 'other universes' or a cosmic phase that preceded the Big Bang. The challenge they face is to match the known cosmic features but, in addition, to give explanations of the anomalies. So far there is no stand-out competitor. It's still a mystery.

***Paul Davies** is a Regents Professor of Physics and Director of the Beyond Center for Fundamental Concepts in Science at Arizona State University*

The Smallest Lights in the Universe: a memoir

Sara Seager
4th Estate
£9.99 ● PB



"Sometimes you need darkness to see," writes astrophysicist Sara Seager, referring to the ability of astronomers to peer into space, but also to the losses that life can bring. "Sometimes you need light."

It is this search for the 'smallest lights in the Universe' that Seager's book beautifully chronicles, as both personal memoir and the story of her quest to explore the Universe. On one side, we get a view of what it's like at the forefront of research: chasing exoplanets, studying the biosignatures of possible alien life, chairing projects for NASA.

On the other, there's a neglectful childhood, a slow-burn love affair, and the dying of Seager's husband from cancer, with its subsequent fallout.

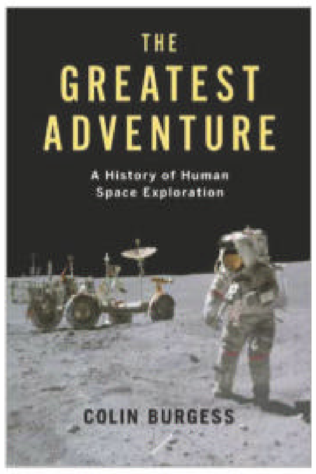
At points the book is romantic, and filled with awe about space in a way that anyone who loves the stars will understand. "There are places where science and magic meet, windows to worlds greater than my own," writes Seager. A professor of physics and planetary science at MIT, she has contributed to the foundations of exoplanet research and won the MacArthur Foundation's "genius" grant.

The book's strength lies in its intersection with human life: grief, sadness and hope. Seager believes there is life elsewhere in the Universe, but she also asks what that search says about us, reminding us that we are "capable of wonder and wonderful things". ★★★★★

***Shaoni Bhattacharya** is a science writer and journalist*

The Greatest Adventure

Colin Burgess
Reaktion Books
£25 ● HB



Those fascinated with space exploration and the many human endeavours to leave Earth's atmosphere never tire of hearing the stories and events of these missions told over again, discovering new, details that enrich the history further.

The Greatest Adventure covers the entire history of human space exploration from the early events that ignited the Space Race between the Soviets and US, all the way through to the International Space Station, the Soyuz rockets and Space Shuttles, to the present, with the prospect of space tourism and private companies playing greater roles. It concludes with a brief reflection on what the future holds.

Those well versed in human spaceflight will find it an enjoyable read, uncovering new details that the author has packed into the book. Equally, if you are new to this topic, the book provides a wonderful overview of space exploration.

One notable absence is a lack of character insights into the people behind these space-faring pursuits. At points, this can make it difficult to paint the more human story that has really driven the achievements of the past 60 years.

However, to include such accounts would probably have meant sacrificing such comprehensive coverage of events, and there are plenty of biographies and other literature referenced to jump off into.

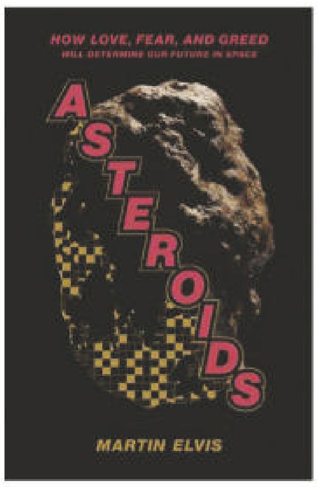
The Greatest Adventure provides an excellent springboard from which to do so. It's an all-round good read. ★★★★☆

***Nisha Beerjeraz-Hoyle** is a space and astronomy writer*

Asteroids

SPACE ROCK SCIENCE

Martin Elvis
Yale University Press
£20 ● HB



Why should we explore the asteroids? For the love of knowledge? Asteroids can teach us about the formation and evolution of our Solar System, the origins of Earth's oceans, organics and even life, so there's plenty to learn! What about fear? An asteroid impact wiped out the dinosaurs – it might therefore be wise to keep tabs on them and work out the best way to avoid such a fate ourselves. Or perhaps greed? Some asteroids contain water, a valuable commodity in space, while others contain rare or useful metals we could mine to generate a handsome profit.

In the book *Asteroids*, Martin Elvis argues that all three of these factors together – love, fear and greed – make a compelling case for our continued exploration of these Solar System bodies. While early chapters consider the whys, later ones focus on the hows, describing scientific studies of asteroids, our efforts to survey, track and, if necessary, tackle them, and the idea of asteroid prospecting. By including an informative overview of our technological capabilities, referring to relevant budgets and costs throughout, and highlighting the inadequacies of current space law, Elvis makes clear that there are technological, financial and political barriers to overcome in the pursuit of these space rocks. Yet despite this, he remains optimistic and maintains that all three motives together provide the necessary incentive.

Asteroids is a fascinating and, at times, surprising read, packed with useful information and benefitting from Elvis's personal accounts throughout. Written in an engaging and entertaining style, readers will find it hard to put down. ★★★★★

***Dr Penny Wozniakiewicz** is a lecturer in space science at the University of Kent*

Ezzy Pearson rounds up the latest astronomical accessories

GEAR

1 Celestron Ultima Edge flat field 1.25-inch eyepieces

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2 Astro Engineering Rigid 8-inch dew shield

Price £56.90 • **Supplier** Telescope House
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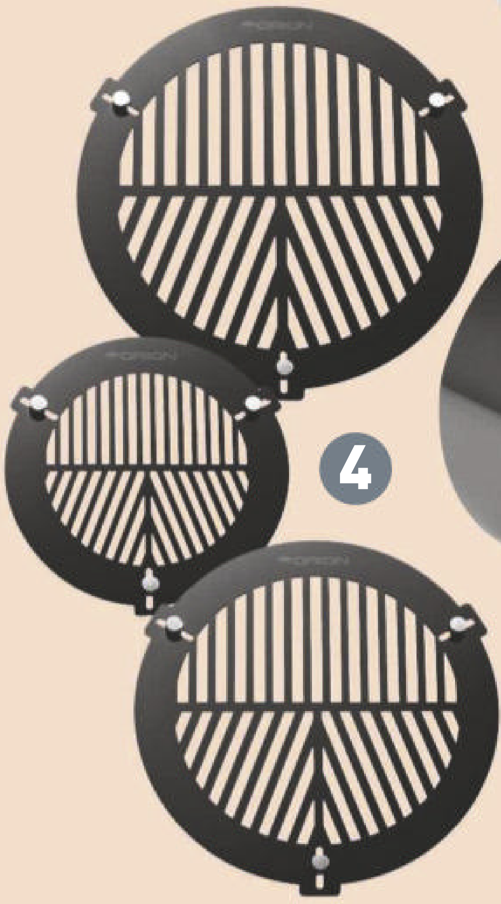
Clear the dew away from your optics and protect your observations from stray light with this shield. It fits around tubes with a diameter between 243mm and 253mm, and it's held in place with nylon screws.

3 StellarMira 2-inch Field-Flattener with M42 adaptor

Price £79 • **Supplier** First Light Optics
Tel 020 3384 5187 • **www.firstlightoptics.com**

Remove the curvature of your scope's view without reducing its focal length using this field-flattener. It's optimised for DSLRs and scopes with a focal ratio of f/5 to f/7 and has an integrated M42 adaptor.



4 Orion PinPoint Astrophotography Telescope Focusing Masks

Price from £26.99 • **Supplier** Orion Telescopes
Tel 0800 041 8146 • **https://uk.telescope.com**

Ensure your astro images have pinpoint focus with the help of these Bahtinov masks. The masks come in a variety of sizes and have three adjustable bolts to ensure a tight fit, no matter what size scope you own.

5 Solar System glow lamps

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https://thedecorhouse.co.uk

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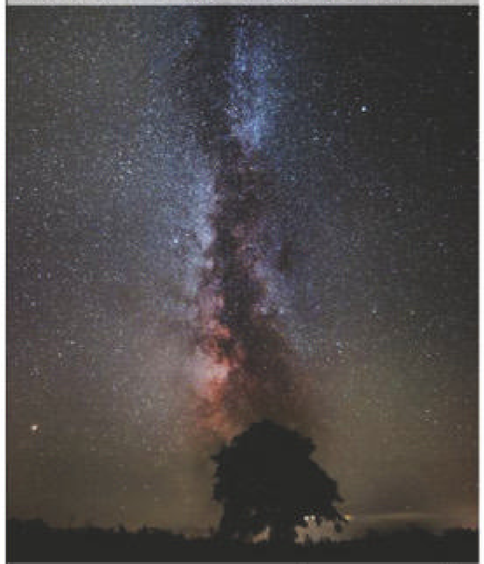

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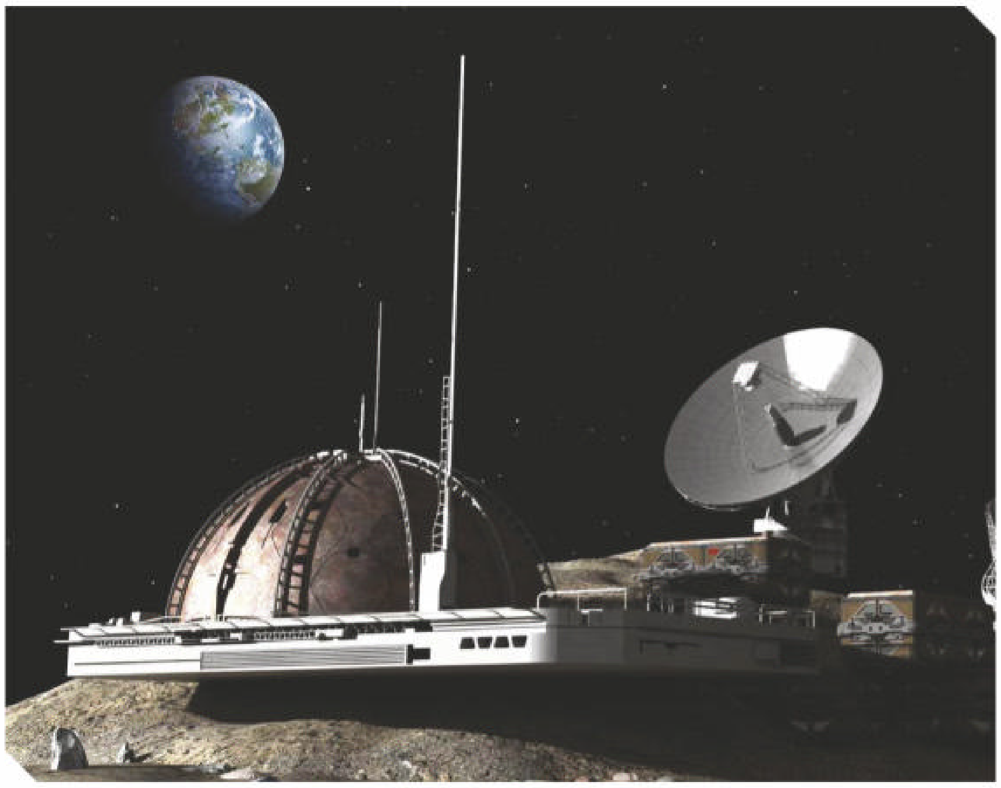
Shaoni Bhattacharya interviews Jekan Thanga

Q&A WITH AN AEROSPACE ENGINEER

Forget the Arctic seed bank, the Lunar Ark could provide the ultimate planetary insurance for our survival

What is the Lunar Ark?
It's a backup storage of Earth's biodiversity on the Moon, inspired by the Svalbard Global Seed Vault. We would store animal sperm and eggs, plant seeds, spores and maybe stem cells. We haven't said we have a total solution, because the restoring process is far from easy! We can't just take the egg and the sperm and say "okay, a new creature's going to come out," without something like a uterus – so those specimens have to be advanced or even artificially made.



▲ The Lunar Ark's cryogenic storage would be powered by solar panels

What's the rationale behind building a Lunar Ark?
I lead a group looking at areas of space exploration, and one of these has been the threat from asteroids. In 2013, the Chelyabinsk meteor came out of nowhere and caused a 500 kiloton explosion (Hiroshima was 15 kilotons) above Russia. Another dangerous threat was the Carrington Event; a solar storm that disrupted Earth's magnetic field in 1859.

What we can take from these examples is that we have to deal with space threats – they are not just science fiction. We are developing systems for early detection, but we've realised that maybe we can't fully contain these problems. We are always thinking about facing a cataclysm rather than avoiding it.

How did the discovery of lunar lava tubes spur on the concept?
Our collaborators at Arizona State University discovered lava tubes on the Moon in 2012. We realised that there is, just 4–5 days away from us, somewhere that has been untouched for 3–4 billion years. This is where we would store the stuff that's most precious in the event of a cataclysm.

What challenges are there in placing the Ark?
There are impacts and craters on the Moon, but it is well-protected because of Earth's bigger size and gravity. We still have the threat of micro-meteorites, but the lava tubes are a natural shield: they are 80–100m below ground, at a constant temperature of –20°C. We envisage storing everything at –180°C or –196°C for cryopreservation. So we need this refrigeration – that's the final piece of engineering we have to figure out. The Svalbard Global Seed Vault is at –18°C, which is specialised enough for seeds. Here, we are going after a more ambitious technology: the idea is to save 6.7 million species. Maybe we can start by replicating Svalbard on the Moon.

How might the Lunar Ark work in practical terms?
To save each species, we need a viable population number, which is anywhere between 50 to 500 individuals. We would keep eggs and sperm in 100ml fluid bags – under half a soft drink can's worth of fluid per species. The total is about five to six train cart-sized compartments with cryopreservation units inside. These carts would need to be about 10m in diameter and 25m-long to fit them on a rocket. These units could then be stored in a way that's similar to a library, but where you could check out a species.

What would you construct on the Moon?
We would transport everything from Earth, so it's prefabricated. The overall size of the building structure is like a small, regional airport, with a runway. We'll also use solar panels to power the Lunar Ark.

If we had a Doomsday event, how would we access the Lunar Ark?
The Ark will need a logistics base, which won't rely on Earth, and its job is to provide emergency transport. Transport back from the Moon to Earth is a lot easier than the other way because of gravity. The main energy barrier is getting off the lunar surface. Then, Earth's gravity dominates. It doesn't get you back in the fastest time, but there's a little fuel involved. We also presume if you are building up a space insurance policy for our prolonged future – that technology will advance. Maybe, 30–40 years from now we'll have other ways of transport – not just rockets.

Dr Jekan Thanga is an assistant professor in the department of aerospace and mechanical engineering at the University of Arizona in Tuscon

3000AD/ALAMY STOCK PHOTO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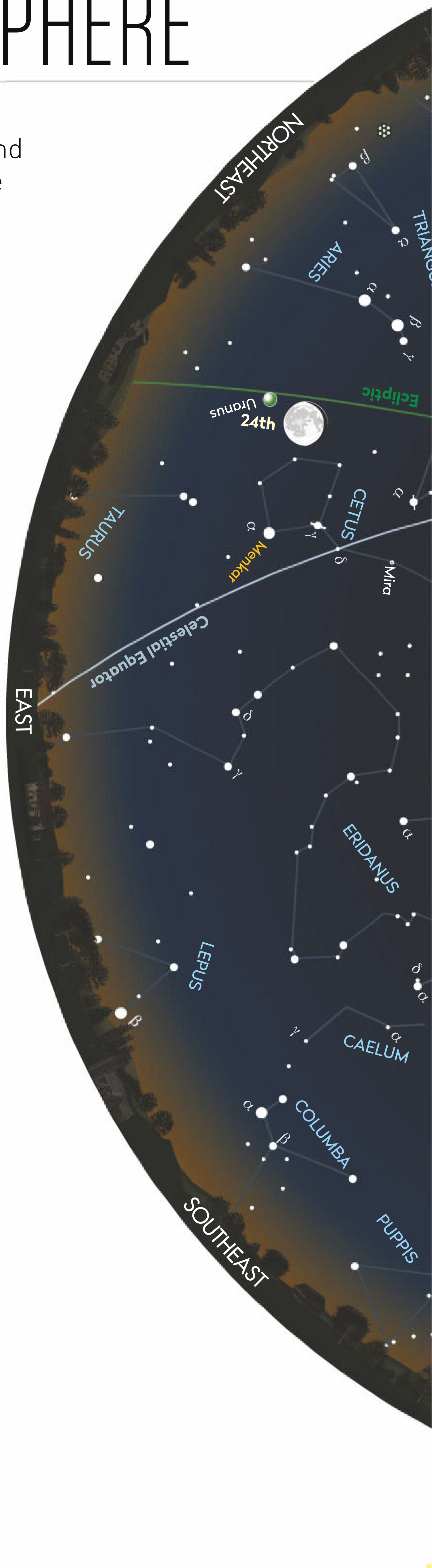
THE SOUTHERN HEMISPHERE

With Glenn Dawes

Welcome Mercury back to the evening skies and discover celestial treasures in Grus, the Crane



When to use this chart

1 Sep at 00:00 AEST (14:00 UT)
15 Sep at 23:00 AEST (13:00 UT)
30 Sep at 22:00 AEST (12:00 UT)

The chart accurately matches the sky on the dates and times shown for Sydney, Australia. The sky is different at other times as the stars crossing it set four minutes earlier each night.

SEPTEMBER HIGHLIGHTS

September sees the best return of Mercury to the evening skies for 2021. This elusive world is rarely visible outside twilight hours, but mid-month is placed 10° above the western horizon at the end of astronomical twilight. Travelling with the bright star Spica (Alpha (α) Virginis) for the last two weeks, Mercury is located below Venus. Its change in phase is also impressive; starting the month with the shape of a nine-day-old Moon, it reduces to that of a three-day-old crescent.

STARS AND CONSTELLATIONS

September is a great time for observing; the spring nights are fairly long – and getting warmer – and being at equinox (on 22 September), we can view a wide selection of targets. The early evening shows Sagittarius, the Archer, and Scorpius, the Scorpion riding high on the back of the Milky Way. If you stay up all night, the predawn sky reveals Orion, the Hunter, with Taurus, the Bull in the north and the Magellanic Clouds in the south.

THE PLANETS

A western sky view reveals Mercury close to the horizon as twilight ends, with Venus higher up. Having just passed opposition, Saturn and Jupiter dominate the northern evening sky, with Saturn transiting (due north) at 21:00 mid-month, and Jupiter following an hour behind. Neptune trails later at opposition and is visible all night. Uranus rises in the evening and is viewed in the morning.

DEEP-SKY OBJECTS

This month we visit the constellation of Grus, the Crane. The double star, Pi (π) Grus (RA 22h, 23.1m, dec. -45° 56') – with mag. +6.6 Pi^1 (π^1) Gruis and mag. +5.8 Pi^2 (π^2) Gruis, separated by 4 arcminutes – is ideal for binoculars. Closer inspection with a telescope reveals Pi Gruis to be a double-double. Pi^1 Gruis consists of mag. +6.6 and mag. +10.8 members – coloured red and yellow respectively – only 2.7 arcseconds apart. Pi^2 Gruis is yellowish with mag. +5.8 and mag. +11.2 stars, separated by an easier 4.8 arcseconds.

Next, we visit Grus's neck to find planetary nebula IC 5148 (RA 21h 59.6m, dec. -39° 12'). It consists of a mag. +11.0, 2-arcminute diameter, circular ring. The surface is a bit mottled, with a dark central region. It lies in a star field with a mag. +10.3 star close to the southern edge.

Chart key

- GALAXY
- OPEN CLUSTER
- GLOBULAR CLUSTER
- PLANETARY NEBULA
- DIFFUSE NEBULOSITY
- DOUBLE STAR
- VARIABLE STAR
- COMET TRACK
- ASTEROID TRACK
- METEOR RADIANT
- QUASAR
- PLANET

STAR BRIGHTNESS:
- MAG. 0 & BRIGHTER
- MAG. +1
- MAG. +2
- MAG. +3
- MAG. +4 & FAINTER

CHART: PETE LAWRENCE


NORTH
NORTHWEST
WEST
SOUTHWEST
SOUTH
CYGNUS
Deneb
LYRA
Ring Nebula
Albireo
Northern Cross
Dumbbell Nebula
Summer Triangle
VULPECULA
SAGITTA
Coathanger Cluster
Altair
AQUILA
Rasalhague
SERPENS CAUDA
OPHIUCHUS
M10
SCUTUM
M11
M16
M17
M25
M23
M22
M20
M8
M19
M7
M6
M62
Antares
M4
12th
SCORPIUS
LIBRA
LUPUS
NORMA
ARA
TRIANGULUM AUSTRALE
CIRCINUS
Rigel Kent
Agena
CENTAURUS
NGC 4833
MUSCA
Coal Sack
Jewel Box
CRUX
Blue Planetary Nebula
η Carina Nebula
Southern Pleiades
CARINA
VOLANS
Canopus
PICTOR
CHAMAELEON
APUS
South Celestial Pole
MENSA
LMC
Tarantula Nebula
DORADO
RETICULUM
HYDRUS
SMC
OCTANS
TUCANA
47 Tucanae
NGC 362
Achernar
HOROLOGIUM
PAVO
INDUS
CORONA AUSTRALIS
SAGITTARIUS
Teapot
15th
PHOENIX
NGC 300
FORNAX
GRUS
IC 5148
PISCIS AUSTRINUS
SCULPTOR
Fomalhaut
NGC 253
Deneb Kaitos
MICROSCOPIUM
M30
Saturn
Pluto
CAPRICORNUS
18th
Jupiter
AQUARIUS
M2
Water Jar
Neptune
21st
Mars
EQUULEUS
M15
Enif
DELPHINUS
Circlet
PISCES
Great Square of Pegasus
PEGASUS
Alpheratz
ANDROMEDA
M31
M32
M110
M33
Blue Snowball
LACERTA
Cocoon Nebula
N. America Nebula
NGC 7027
M39
M29
Veil Nebula

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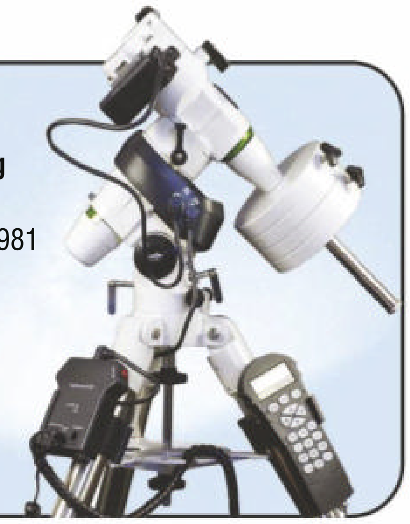

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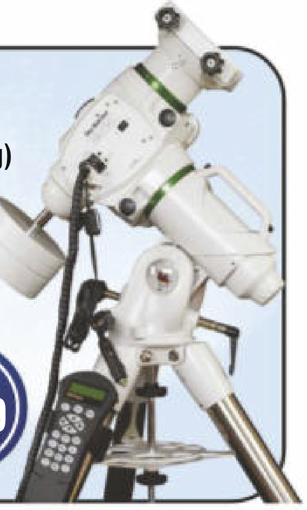

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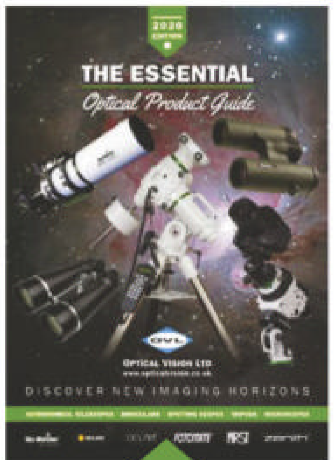

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